

UNIT – 1 ELECTROSTATICS

Important Question

Two Marks	
Book Back	Book inside
1.What are the difference between Coulomb force and gravitational force? 2.The electric field never intersect. Justify 3.Define electric dipole. Give the expression for the magnitude of its electric dipole moment and its direction 4. What is an equipotential surface? 5.What are the Properties of equipotential surfaces? 6.What is meant by electrostatic energy density? 7.What is dielectric strength? 8. Define capacitance. Give its unit 9.What is corona discharge or action at points	1. State Coulomb's law 2.What is dielectric breakdown? 3.Write down the difference between polar and nonpolar molecule. 4.Define electrostatic induction 5.Define Gauss's law 6.Why it is always safer to sit inside a bus than in open ground or under a tree? 7. Give the applications of capacitor.
Three Marks	
1.Derive an expression for electrostatic potential due to point charge 2.Obtain Gauss law from Coulomb's law 3.Obtain expression for electric field due to a charged infinitely plane sheet 4. Derive an expression for Torque experienced by a dipole due to a uniform electric field 5.Obtain the expression for capacitance for a parallel plate capacitor 6. Obtain the expression for energy stored in the parallel plate capacitor 7. Derive the expression for resultant capacitance when capacitors connected in series & in parallel	1. Explain the properties of electric field lines 2.Derive the expression for electric field due two long parallel charged infinite sheets 3. Explain the working of microwave oven.
Five marks	

1. Calculate the electric field due to a dipole on axial and equatorial plane
2. Derive an expression for electrostatic potential due to an electric dipole
3. Obtain expression for electric field due to an infinitely long charged wire
4. Explain in detail the construction and working of a van de Graff generator
5. Explain in detail effect of a dielectric placed in parallel plate capacitor

Important Formulae

1. Electrostatic force between charges q_1

and q_2 , $\vec{F}_{12} = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2} \hat{r}_{21}$ (**Vector form**)

2. **Equivalent capacitance**

(i) **C_1 and C_2 in series**

$$C_s = \frac{C_1 C_2}{C_1 + C_2}; \frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$

(ii) **C_1 and C_2 in parallel**

$$C_p = C_1 + C_2$$

3. Potential energy due to system of three

$$\text{charge } U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_2}{r_{12}} + \frac{q_2 q_3}{r_{23}} + \frac{q_1 q_3}{r_{13}} \right)$$

4. Total charge $q = n \times e$

5. Electric flux: $\phi_E = \frac{q}{\epsilon_0} = \vec{E} \cdot \vec{A} = EA \cos \theta$

6. Relative permittivity or Dielectric

$$\text{constant } \epsilon_r = \frac{\epsilon(\text{permittivity of medium})}{\epsilon_0(\text{permittivity of vacuum})}$$

7. Force between charges in medium: $F_m =$

$$\frac{F_{\text{air}}}{\epsilon_r}$$

8. Electric field $E = \frac{\text{force}}{\text{charge}} = \frac{F}{q} \Rightarrow F = qE$

9. Electric field due to a point charge:

$$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$$

10. Electric dipole moment, $\vec{p} = q \times 2a\hat{a}$

11. Magnitude of torque

$$\tau = \vec{p} \times \vec{E} = pE \sin \theta \quad (p = q \times 2a)$$

12. Electric potential at a point due to a

$$\text{point charge, } V = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$

13. Electric potential energy of dipole $U =$

$$-pE \cos \theta = -\vec{p} \cdot \vec{E}$$

14. Electric potential at a point due to an

$$\text{electric dipole } V = \frac{p}{4\pi\epsilon_0} \frac{\cos \theta}{r^2}$$

15. Surface Charge density, $\sigma = \frac{q}{A}$: Linear

$$\text{charge density } \lambda = \frac{q}{l}$$

16. Work done by a charge $W = qV$

17. Capacitance of a conductor $C = \frac{q}{V}$ [q – charge, V – potential]

18. (i) Capacitance of a parallel plate

$$\text{capacitor without dielectric } C = \frac{\epsilon_0 A}{d}$$

(ii) with the dielectric completely filled

$$\text{the capacitor } C' = \frac{\epsilon_0 \epsilon_r A}{d} = C \times \epsilon_r$$

19. Energy stored in a capacitor

$$E = \frac{1}{2} CV^2 \text{ or } \frac{1}{2} qV \text{ or } \frac{1}{2C} q^2$$

Points To Remember

- Potential due to the dipole falls faster than that due to a point charge
- Electric Field_{Equatorial} = 2E_{axial}
- Potential due to a point charge
 - ✓ For positive charge - decreases as the distance increases
 - ✓ For negative charge - increases as the distance increases
 - ✓ At infinity V = 0
- Potential due to a (i) point charge $V \propto \frac{1}{r}$ (ii) dipole $V \propto \frac{1}{r^2}$
- Electric field due to

<i>Point charge</i>	<i>Dipole</i>	<i>Infinite long straight charged wire</i>	<i>Plane sheet of charge</i>	<i>Uniformly charged sphere</i>
$E = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2}$	Axial $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{2\vec{p}}{r^3}$ Equatorial $\vec{E} = \frac{-1}{4\pi\epsilon_0} \frac{\vec{p}}{r^3}$	$E = \frac{\lambda}{2\pi\epsilon_0 r}$	$E = \frac{\sigma}{2\epsilon_0}$ Between two plates Inside: $E = \frac{\sigma}{\epsilon_0}$ Outside: $E = 0$	Outside $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \hat{r}$ On the sphere $E = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2} \hat{r}$ Inside $E = 0$

6. Effect of dielectrics in capacitors

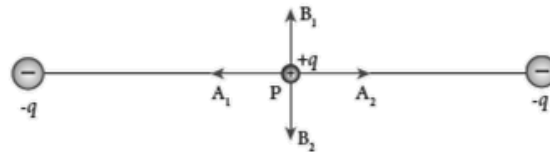
<i>S. No</i>	<i>Dielectric is inserted</i>	<i>Charge Q</i>	<i>Voltage V</i>	<i>Electric field E</i>	<i>Capacitance C</i>	<i>Energy U</i>
1	When the battery is disconnected	Constant	decreases	Decreases	Increases	Decreases
2	When the battery is connected	Increase	Constant	Constant	Increases	Increases

Values and Units

- Value of $\epsilon_0 = 8.854 \times 10^{-12} \text{C}^2 \text{N}^{-1} \text{m}^{-2}$
- (i) $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{Nm}^2 \text{C}^{-2}$,
 (ii) $\frac{1}{\epsilon_0} = 1.129 \times 10^{11}$
- $e = 1.6 \times 10^{-19} \text{C}$
- 1 micro farad = 10^{-6} farad ,
 1 Pico farad = 10^{-12} farad
- Permittivity of medium (ϵ): $\text{C}^2 \text{N}^{-1} \text{m}^{-2}$
- Electric flux: $\text{Nm}^2 \text{C}^{-2}$
- Electric field (E): NC^{-1} or Vm^{-1}
- Electric potential (V): JC^{-1} or volt
- Value of Relative permittivity of air: 1 (no unit)
- Unit of Capacitance (C): farad

Textbook One Marks Solved

1. Two identical point charges of magnitude $-q$ are fixed as shown in the figure below. A third charge $+q$ is placed midway between the two charges at the point P. Suppose this charge $+q$ is displaced a small distance from the point P in the directions indicated by the arrows, in which direction(s) will $+q$ be stable with respect to the displacement?



- (a) A_1 and A_2 (b) B_1 and B_2 (c) both directions (d) No stable

Hint: θ between B_1 & B_2 is 90° . $V = \frac{p \cos \theta}{4\pi\epsilon_0 r^2} \rightarrow V = 0$. $W = V \cdot q = 0$

Answer: (b) B_1 and B_2

2. Which charge configuration produces a uniform electric field?

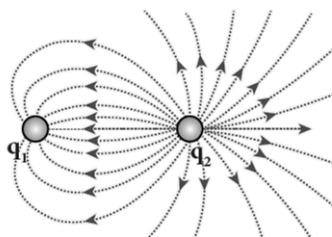
- (a) point Charge (b) infinite uniform line charge
(c) uniformly charged infinite plane (d) uniformly charged spherical shell

Hint: Electric field due to uniformly charged infinite plane ($E = \frac{\sigma}{2\epsilon_0}$) does not contain r term, remaining will contains ' r ' (distance) term.

Answer: (c) uniformly charged infinite plane

3. What is the ratio of the charges $\left| \frac{q_1}{q_2} \right|$ for the following electric field line pattern?

- (a) 1/5 (b) 25/ 11 (c) 5 (d) 11/ 25



Hint: No of lines entering $q_1 = 11$. No of lines entering $q_2 = 25$

$$\left| \frac{q_1}{q_2} \right| = \frac{11}{25}$$

Answer: (d) 11/ 25

4. An electric dipole is placed at an alignment angle of 30° with an electric field of $2 \times 10^5 \text{ N C}^{-1}$. It experiences a torque equal to 8 N m. The charge on the dipole if the dipole length is 1 cm is

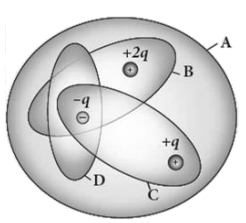
- (a) 4 mC (b) 8 mC (c) 5 mC (d) 7 mC

Hint: $\tau = pE \sin \theta = 2qa (E \sin \theta)$. Given $\theta = 30^\circ$, $E = 2 \times 10^5$, $\tau = 8$, $2a = 1 \times 10^{-2} \text{ m}$

$$q = \frac{\tau}{2a E \sin \theta} = 8 \text{ mC}$$

Answer: (b) 8 mC

5. Four Gaussian surfaces are given below with charges inside each Gaussian surface. Rank the electric flux through each Gaussian surface in increasing order.

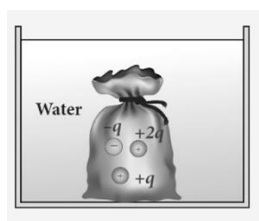


- (a) $D < C < B < A$ (b) $A < B = C < D$ (c) $C < A = B < D$ (d) $D > C > B > A$

Hint: Net charge of A : $3q - q = 2q$ similarly net charge on B,C & D is $q, 0, -q$; $\phi_E = \frac{q}{\epsilon_0}$

Answer: (a) $D < C < B < A$

6. The total electric flux for the following closed surface which is kept inside water



- (a) $\frac{80q}{\epsilon_0}$ (b) $\frac{q}{40\epsilon_0}$ (c) $\frac{q}{80\epsilon_0}$ (d) $\frac{q}{160\epsilon_0}$

Hint: Net charge = $-q + q + 2q = 2q$, ϵ_r of water is 80

$$\phi_{\text{net}} = \frac{q}{\epsilon_r \epsilon_0} = \frac{q}{40\epsilon_0}$$

Answer: (b) $\frac{q}{40\epsilon_0}$

7. Two identical conducting balls having positive charges q_1 and q_2 are separated by a center to center distance r . If they are made to touch each other and then separated to the same distance, the force between them will be

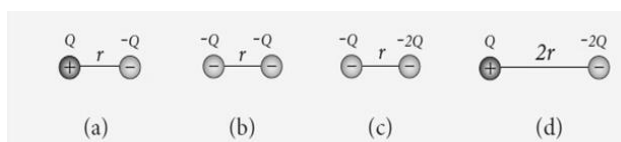
- (a) less than before (b) same as before
(c) more than before (d) zero

Hint: We all know that force is directly proportional to charge

When they are separated, the magnitude of charge will be increased

Answer: (c) more than before

8. Rank the electrostatic potential energies for the given system of charges in increasing order.



- (a) $1 = 4 < 2 < 3$ (b) $2 = 4 < 3 < 1$ (c) $2 = 3 < 1 < 4$ (d) $3 < 1 < 2 < 4$

Hint: $U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$

For a: $U = \frac{1}{4\pi\epsilon_0} \frac{-Q^2}{r}$, For b: $U = \frac{1}{4\pi\epsilon_0} \frac{Q^2}{r}$, For c: $U = \frac{1}{4\pi\epsilon_0} \frac{2Q^2}{r}$, For d: $U = \frac{1}{4\pi\epsilon_0} \frac{-Q^2}{r}$

Answer: (a) $1 = 4 < 2 < 3$

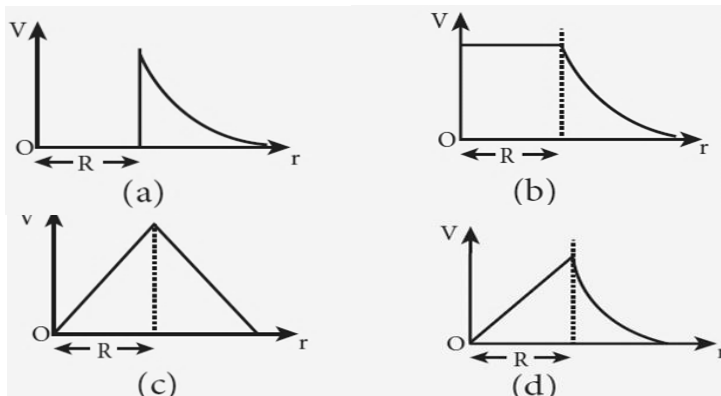
9. An electric field $\vec{E} = 10x\hat{i}$ exists in a certain region of space. Then the potential difference $V = V_o - V_A$, where V_o is the potential at the origin and V_A is the potential at $x = 2$ m is:

- (a) 10 V (b) -20 V (c) +20 V (d) -10 V

Hint: $E = -\frac{dv}{dx}$ $dv = -10x dx$. On integration $V_o - V_A = 20V$

Answer: (c) +20 V

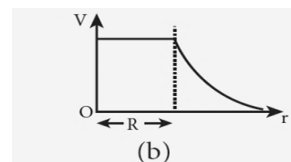
10. A thin conducting spherical shell of radius R has a charge Q which is uniformly distributed on its surface. The correct plot for electrostatic potential due to spherical shell is



Hint: For option b potential

decreased outside the spherical shell as distance increases

Answer: (b)



11. Two points A and B are maintained at a potential of 7 V and -4 V respectively. The work done in moving 50 electrons from A to B is

- (a) $8.80 \times 10^{-17} \text{ J}$ (b) $-8.80 \times 10^{-17} \text{ J}$ (c) $4.40 \times 10^{-17} \text{ J}$ (d) $5.80 \times 10^{-17} \text{ J}$

Hint: $V = 7 - (-4) = 11V$.

$w = q \cdot V = (ne)V = 50 \times 1.6 \times 10^{-19} \times 11 = 8.8 \times 10^{-17} \text{ J}$

Answer: (a) $8.80 \times 10^{-17} \text{ J}$

12. If voltage applied on a capacitor is increased from V to $2V$, choose the correct conclusion.

- (a) Q remains the same, C is doubled (b) Q is doubled, C doubled

(c) C remains same, Q doubled

(d) Both Q and C remain same

Hint: $Q = CV$ i.e $Q \propto V$ when V changes Q changes

Answer: (c) C remains same, Q doubled

13. A parallel plate capacitor stores a charge Q at a voltage V. Suppose the area of the parallel plate capacitor and the distance between the plates are each doubled then which is the quantity that will change?

(a) Capacitance

(b) Charge

(c) Voltage

(d) Energy density

Hint: Area A changes to 2A, distance d changes to 2d

$$\text{Capacitance } C = \frac{\epsilon_0 A}{d} = C = \frac{\epsilon_0 2A}{2d} = \frac{\epsilon_0 A}{d} \text{ (same)}$$

Charge $Q \propto V$ V remains same so Q remains same

$$\text{Potential } V = \frac{Q}{C} = \frac{Qd}{\epsilon_0 A} = \frac{Q \times 2d}{\epsilon_0 2A} = \frac{Qd}{\epsilon_0 A} \text{ (same)}$$

$$U_E = \frac{1}{2} \epsilon_0 E^2 A d = \frac{1}{2} \epsilon_0 E^2 \times 2A \times 2d \text{ (It changed by four times)}$$

Answer: (d) Energy density

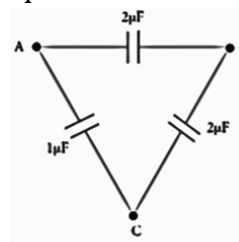
14. Three capacitors are connected in triangle as shown in the figure. The equivalent capacitance between the points A and C is

(a) $1 \mu\text{F}$

(b) $2 \mu\text{F}$

(c) $3 \mu\text{F}$

(d) $1/4 \mu\text{F}$



Hint:

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{2} + \frac{1}{2} = 1$$

$$C_p = C_1 + C_s = 1 + 1 = 2 \mu\text{F}$$

Answer: (b) $2 \mu\text{F}$

15. Two metallic spheres of radii 1 cm and 3 cm are given charges of $-1 \times 10^{-2} \text{C}$ and $5 \times 10^{-2} \text{C}$ respectively. If these are connected by a conducting wire, the final charge on the bigger sphere is

(a) $3 \times 10^{-2} \text{C}$

(b) $4 \times 10^{-2} \text{C}$

(c) $1 \times 10^{-2} \text{C}$

(d) $2 \times 10^{-2} \text{C}$

Hint: $V = \frac{kQ}{r}$; $V_1 = \frac{kQ_1}{3}$ $V_2 = \frac{kQ_2}{1}$ $V_1 = V_2$ which implies $3Q_2 = Q_1$

$$Q_1 + Q_2 = 4 \times 10^{-2} \text{C} \text{ On solving}$$

Answer: (a) $3 \times 10^{-2} \text{C}$

Additional One Marks Solved

1. Three point charges each +q are placed at the corner of an equilateral triangle of side a the electric field at the circumference coil be

a) $\frac{q}{4\pi\epsilon_0 r}$

b) $\frac{q}{4\pi\epsilon_0 r^2}$

c) q/r^2

d) Zero

2. If electric field is through an area 3 m^2 saying in $1/2$ plane then the electric flux due to the electric field in a region is given by $\vec{E} = 3\vec{i} + 4\vec{j} \text{ NC}^{-1}$ is

a) 3

b) 9

c) 18

d) 6

Solution: $\phi_E = \vec{E} \cdot \vec{A} = (3\vec{i} + 4\vec{j}) \cdot 3\vec{i} = 9$

3. Two charged conducting spheres of radii R_1 and R_2 separated by a large distance are connected by a wire. The ratio of the charges on them is

a) $\frac{R_2}{R_1}$

b) $\frac{R_1}{R_2}$

c) $\frac{R_1^2}{R_2^2}$

d) $\sqrt{\frac{R_1}{R_2}}$

Solution:

Since the two spheres are connected they have the same potential.

$$\frac{q_1}{4\pi\epsilon_0 R_1} = \frac{q_2}{4\pi\epsilon_0 R_2}$$

$$\frac{q_1}{q_2} = \frac{R_1}{R_2}$$

4. The effective capacitance of a system in which n identical capacitors having capacitance 'C' are connected in series is

a) nC

b) $\frac{C}{n^2}$

c) $\frac{C}{n}$

d) $n^2 C$

5. The equivalent capacitance for the three capacitors of capacitances 3,3,13 connected in parallel

a) $38 \mu\text{F}$

b) $19 \mu\text{F}$

c) $9 \mu\text{F}$

d) $11 \mu\text{F}$

Solution:

$$C_p = C_1 + C_2 + C_3 = 3 + 3 + 13 = 19 \mu\text{F}$$

6. The maximum potential difference created by Van de Graaff generator of radius of a hollow sphere 0.5m and dielectric strength of air is $3 \times 10^6 \text{Vm}^{-1}$ is

a) 1.5 V

b) 1.5 Million volt

c) 1.5 kV

d) 1.25 V

Solution: $R = 0.5, E_{\text{max}} = 3 \times 10^6$

$$V_{\text{Max}} = E_{\text{Max}} \times R = 1.5 \times 10^6 \text{V} = 1.5 \text{ million volt}$$

7. Consider a neutral conducting sphere. A positive charge is placed outside the sphere. The net charge on sphere is then

a) negative charge is distributed uniformly over the surface of the sphere.

b) negative charge is not distributed uniformly over the surface of the sphere.

c) negative charge appears only at the point charge

d) Zero

Solution:

When a point charge is placed outside the neutral conducting sphere, the net charge is zero.

8. Two capacitors of equal capacitance are first connected in parallel and then in series. The ratio of the total capacities in two cases would be

- a) 1:2 b) 1:4 c) 4:1 d) 2:1

Solution:

$$C_p = 2C, C_s = \frac{C}{2}$$

$$\frac{C_p}{C_s} = \frac{2C}{\frac{C}{2}} = \frac{4}{1} = 4:1$$

9. Van de Graff generator works on the principle of

(a) electromagnetic induction & action at points

(b) electrostatic induction & action at points

(c) electrostatic induction only

(d) action at points only

10. The sample of HCl gas of dipole moment 3.4×10^{-30} is placed in a uniform electric field of magnitude 3×10^4 . The maximum torque experienced by each HCl molecule is

- a) **$10.2 \times 10^{-26} \text{ Nm}$** b) $10.2 \times 10^{-27} \text{ Nm}$
c) $10.2 \times 10^{-25} \text{ Nm}$ d) $10.2 \times 10^{-24} \text{ Nm}$

Solution: $P = 3.4 \times 10^{-30}$, $E = 3 \times 10^4$, Maximum means $\theta = 90^\circ$. $\tau = PE \sin \theta$

11. The electric flux through the rectangle of sides 5 cm and 10 cm kept in the region of a uniform electric field 100 NC^{-1} of angle $\theta = 60^\circ$ is

- a) **$0.25 \text{ Nm}^2 \text{ C}^{-1}$** b) $2.5 \text{ Nm}^2 \text{ C}^{-1}$ c) $0.025 \text{ Nm}^2 \text{ C}^{-1}$ d) $0.0025 \text{ Nm}^2 \text{ C}^{-1}$

Solution: $A = 5 \times 10^{-2} \text{ m} \times 10 \times 10^{-2} \text{ m} = 50 \times 10^{-4} \text{ m}^2$, $E = 100$, $\theta = 60^\circ$, $\cos 60^\circ = \frac{1}{2}$

$$\phi_E = EA \cos \theta = 0.25 \text{ Nm}^2 \text{ C}^{-1}$$

12. The number of electrons will have a charge of one coulomb is

- a) **6.25×10^{18}** b) 6.25×10^{19} c) 1.6×10^{18} d) 1.6×10^{19}

Solution: Number of electron $n = \frac{q}{e} = \frac{1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$

13. The capacitance of a parallel plate capacitor has square plates of side 5 cm and separated by a distance of 1 mm is

- a) **22.12F** b) 22.12mF c) 22.12 μ F d) 22.12kF

Solution: $A = 5 \times 10^{-2} \times 5 \times 10^{-2} \text{ m}^2$, $d = 1 \text{ mm} = 1 \times 10^{-3} \text{ m}$, $\epsilon_0 = 8.854 \times 10^{-12}$

$$C = \frac{\epsilon_0 A}{d} = 22.12 \times 10^{-12} \text{ F} = 22.12 \text{ pF}$$

14. The work done in placing a charge $8 \times 10^8 \text{ C}$ on a capacitor of capacitance $100 \mu\text{F}$ is

- a) $16 \times 10^{-32} \text{ J}$ b) $4 \times 10^{-16} \text{ J}$ **c) $64 \times 10^{-32} \text{ J}$** d) $32 \times 10^{-16} \text{ J}$

Solution:

$$W = Q \times V = Q \times \frac{Q}{C} = \frac{Q^2}{C}$$

$$W = \frac{(8 \times 10^{-18})^2}{100 \times 10^{-6}} = \mathbf{64 \times 10^{-32} \text{ J}}$$

15. Three capacitors each of capacitance C and of break down voltage V are joined in series.

The capacitance and breakdown voltage of the combination will be

- a) $3C, V$ **b) $\frac{C}{3}, 3V$** c) $3C, 3V$ d) $\frac{C}{3}, \frac{V}{3}$

Solution:

$$\frac{1}{C_s} = \frac{1}{C} + \frac{1}{C} + \frac{1}{C} = \frac{3}{C} \rightarrow C_s = \frac{C}{3}$$

$$V_s = V_1 + V_2 + V_3 = V + V + V = 3V$$

$$\therefore V_s = 3V$$

16. An electric dipole is placed at angle of 30° with an electric field of $2 \times 10^5 \text{ NC}^{-1}$. Its length is 2 cm and if it experiences a torque about 4 Nm then its charge is

- a) 8 mC **b) 2 mC** c) 5 mC d) 7 mC

Solution:

$$2l = 2 \times 10^{-2} \text{ m}, \theta = 30^\circ, \tau = 4 \text{ Nm}$$

$$\tau = PE \sin \theta = (q \times 2l) \times E \times \sin \theta$$

$$q = \frac{\tau}{(2l) \times E \times \sin \theta} = \frac{4}{2 \times 10^{-2} \times 2 \times 10^5 \times \sin 30^\circ} = 2 \times 10^{-3} = 2 \text{ mC}$$

17. In a region potential is $V = (6x - 8xy - 8y + 6yz) \text{ V}$ in V and x, y and z are in m . The electric force experienced by a charge of 2 C situated at $(1, 1, 1)$ is

- a) 24 N **b) $4\sqrt{35} \text{ N}$** c) $6\sqrt{5} \text{ N}$ d) 30 N

Solution:

$$\vec{E} = - \left[\left(\frac{\partial V}{\partial x} \right) \hat{i} + \left(\frac{\partial V}{\partial y} \right) \hat{j} + \left(\frac{\partial V}{\partial z} \right) \hat{k} \right]$$

$$V = 6x - 8xy - 8y + 6yz$$

$$\text{At point } (1, 1, 1) \rightarrow E_y = - \frac{\partial V}{\partial y} = -[-8x - 8 + 6z] = -(-8 - 8 + 6) = +10$$

$$\text{At point } (1, 1, 1) \rightarrow E_z = - \frac{\partial V}{\partial z} = -[+6y] = -6(1) = -6$$

$$|\vec{F}| = q|\vec{E}| = 2\sqrt{(2)^2 + (10)^2 + (-6)^2} = 2\sqrt{4 + 100 + 36} = 2\sqrt{140} = 4 \times \sqrt{35} \text{ N}$$

18. At a large distance (r), the electric field due to a dipole varies as

- a) $\frac{1}{r}$ b) $\frac{1}{r^2}$ **c) $\frac{1}{r^3}$** d) $\frac{1}{r^4}$

19. The total electric flux coming out of a unit positive charge placed in air is

- a) ϵ_0 **b) ϵ_0^{-1}** c) $(4\pi\epsilon_0)^{-1}$ d) $4\pi\epsilon_0$

20. The total flux over a closed surface enclosing a charge q (in $\text{Nm}^2 \text{C}^{-1}$)

- a) $8\pi q$ b) $9 \times 10^9 q$ **c) $36\pi \times 10^9 q$** d) $8.854 \times 10^{-12} q$

Solution:

$$\Phi_E = \frac{q}{\epsilon_0} = \frac{q}{1/4\pi \times 9 \times 10^9} = 36\pi \times 10^9 q$$

21. The ratio of the force between two charges in air and that in a medium of dielectric constant K is

- a) $K: 1$** b) $1: K$ c) $K^2: 1$ d) $1: K^2$

22. A force of 0.01 N is exerted on a charge of $1.2 \times 10^{-5} \text{ C}$ at a certain point. The electric field at that point is

- a) $5.3 \times 10^4 \text{ NC}^{-1}$ b) $8.3 \times 10^4 \text{ NC}^{-1}$
c) $5.3 \times 10^{-4} \text{ NC}^{-1}$ **d) $8.3 \times 10^2 \text{ NC}^{-1}$**

Solution:

$$E = \frac{F}{q} = \frac{0.01}{1.2 \times 10^{-5}} = 8.3 \times 10^2 \text{ NC}^{-1}$$

23. The electric field intensity at a point 20 cm away from a charge of $2 \times 10^{-5} \text{ C}$ is

- a) $4.5 \times 10^6 \text{ NC}^{-1}$** b) $3.5 \times 10^5 \text{ NC}^{-1}$
c) $3.5 \times 10^6 \text{ NC}^{-1}$ d) $4.5 \times 10^5 \text{ NC}^{-1}$

Solution:

$$E = \frac{q}{4\pi\epsilon_0 r^2} = \frac{9 \times 10^9 \times 2 \times 10^{-5}}{(0.2)^2} = 4.5 \times 10^6 \text{ NC}^{-1}$$

24. A $1 \mu\text{F}$ capacitor is placed in parallel with a $2 \mu\text{F}$ capacitor across a 100 V supply. The total charge on the system is

- a) $\frac{100}{3} \mu\text{C}$ b) $100 \mu\text{C}$ c) $150 \mu\text{C}$ **d) $300 \mu\text{C}$**

Solution:

Equivalent capacitor = $1 + 2 = 3 \mu\text{F}$. Total charge, $q = CV = 3 \times 100 = 300 \mu\text{C}$

25. A parallel plate capacitor of capacitance $100 \mu\text{F}$ is charged to 500 V . The plate separation is then reduce to half of its original value. Then the potential on the capacitor becomes

- a) 250 V** b) 500 V c) 1000 V d) 2000 V

Solution:

Here, $C' = 2C$, since the charge remains the same.

$$q = C'V' = CV \Rightarrow V' = \frac{CV}{2C} = \frac{500}{2} = 250 \text{ V}$$

26. A point charge q is rotating around a charge Q in a circle of radius r . The work done on it by the coulomb forces is

- a) $2\pi r q$ b) $2\pi Q q$ c) $\frac{Q}{2\epsilon_0 r}$ **d) Zero**

27. Capacitance of a parallel plate capacitor can be increased by

- a) increasing the distance between the plates
b) increasing the thickness of the plates
c) decreasing the thickness of the plates

d) decreasing the distance between the plates

28. Two charges are placed in a vacuum at a distance d apart. The force between them is F . If a medium of dielectric constant 2 is introduced between them, the force will now be

- a) $4F$ b) $2F$ c) $\frac{F}{2}$ **d) $\frac{F}{4}$**

29. Two isolated, charged conducting spheres of radii R_1 and R_2 produce the same electric field near their surfaces. The ratio of electric potentials on their surfaces is

- a) $\frac{R_1}{R_2}$** b) $\frac{R_2}{R_1}$ c) $\frac{R_1^2}{R_2^2}$ d) $\frac{R_2^2}{R_1^2}$

30. An electric charge is placed at the centre of a cube of side a . The electric flux through one of its faces will be

- a) $\frac{q}{6\epsilon_0}$** b) $\frac{q}{\epsilon_0 a^2}$ c) $\frac{q}{4\pi\epsilon_0 a^2}$ d) $\frac{q}{\epsilon_0}$

Solution: According to Gauss's law, the electric flux through the cube is $\frac{q}{\epsilon_0}$. Since there are six faces, the flux through one face is $\frac{q}{6\epsilon_0}$.

31. An electric dipole is placed in a uniform electric field with its axis parallel to the field. It experiences

- a) only a net force **b) neither a net force nor a torque**
c) both a net force and torque d) only a torque

32. A particle of charge q is placed at rest in a uniform electric field E and then released. The kinetic energy attained by the particle after moving a distance y is

- a) qE^2y b) q^2Ey c) qEy^2 **d) qEy**

Solution:

Force on the particle = qE

KE = work done by the force = $F \cdot y = qEy$

33. Electric potential energy of an electric dipole in an electric field is given as

- a) $pE \sin \theta$ b) $-pE \sin \theta$ **c) $-pE \cos \theta$** d) $pE \cos \theta$

34. A point charge $+q$ is placed at the midpoint of a cube of side l . The electric flux emerging from the cube is

- a) $\frac{q}{\epsilon_0}$** b) $\frac{6ql^2}{\epsilon_0}$ c) $\frac{q}{6\epsilon_0 l^2}$ d) $\frac{C^2 V^2}{2}$

35. If the electric field in a region is given by $\vec{E} = 5\hat{i} + 4\hat{j} + 9\hat{k}$, then the electric flux through a surface of area 20 units lying in the $y - z$ plane will be

- a) 20 units b) 80 units **c) 100 units** d) 180 units

Solution:

The area vector $\vec{A} = 20\hat{i}$; $\vec{E} = (5\hat{i} + 4\hat{j} + 9\hat{k})$

Flux (ϕ) = $\vec{E} \cdot \vec{A} = 5 \times 20 = 100$ units

36. A point Q lies on the perpendicular bisector of an electric dipole of dipole moment P . If the distance of Q from the dipole is r , then the electric field at Q is proportional to

- a) p^{-1} and r^{-2} b) p and r^{-2} **c) p and r^{-3}** d) p^2 and r^{-3}

37. The work done in moving $4\mu\text{C}$ charge from one point to another in an electric field is 0.012J. The potential difference between them is

- a) 3000 V** b) 6000 V c) 30 V d) 48×10^3 V

Solution:

$$V = \frac{W}{q} = \frac{0.012}{4 \times 10^{-6}} = 3000$$

38. The electric field outside the two oppositely charged plane sheets each of charge density σ is

- a) $\frac{\sigma}{2\epsilon_0}$ b) $-\frac{\sigma}{\epsilon_0}$ c) $\frac{\sigma}{\epsilon_0}$ **d) zero**

Solution:

$$E = \frac{\sigma}{\epsilon_0} + \left(-\frac{\sigma}{\epsilon_0}\right) = 0$$

39. Torque on a dipole in a uniform electric field is maximum when angle between P and E is

- a) 0° **b) 90°** c) 45° d) 180°

Solution: $\tau = pE \sin \theta$. $\sin \theta$ will be maximum when it is 90°

40. A hollow metallic spherical shell carrying an electric charge produces no electric field at points

- a) on the surface of the sphere **b) inside the sphere**
c) at infinite distance from the centre of the sphere d) outside the sphere

41. Potential energy of two equal negative point charges of magnitude $2\mu\text{C}$ placed 1 m apart in air is

- a) 2 J b) 0.36 J c) 4 J **d) 0.036 J**

Solution:

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r} = \frac{9 \times 10^9 \times 2 \times 10^{-6} \times 2 \times 10^{-6}}{1} = .036$$

42. Twenty seven water drops of the same size are charged to the same potential. If they are combined to form a big drop, the ratio of potential of the big drop to that of a small drop is

- a) 3 b) 6 **c) 9** d) 27

Solution: $V' = n^{2/3} V \Rightarrow \frac{V'}{V} = (27)^{2/3} = 9$

43. The direction of electric field at a point on the equatorial line due to an electric dipole is

- a) along the equatorial line towards the dipole
b) along the equatorial line away from the dipole
c) parallel to the axis of the dipole and opposite to the direction of dipole moment
d) parallel to the axis of the dipole and in the direction of dipole moment.

43. The number of electric lines of force originating from a charge of 1 micro coulomb is

- a) 1.129×10^5** b) 1.6×10^{-18} c) 6.25×10^{18} d) 8.85×10^{-12}

Solution:

$$N = \frac{q}{\epsilon_0} = 1 \times 10^{-6} \times 1.29 \times 10^{11} = 1.129 \times 10^5$$

44. An electric dipole placed at an angle θ in a non-uniform electric field experiences a

- a) neither a force nor a torque b) torque only
c) both force and torque d) force only

45. A capacitor of capacitance $6\mu\text{F}$ is connected to a 100 V battery. The energy stored in the capacitor is

- a) 30 J b) 3J **c) 0.03 J** d) 0.06 J

Solution: $E = \frac{1}{2} CV^2 = \frac{1}{2} \times 6 \times 10^{-6} \times 100^2 = 0.03 \text{ J}$

46. The capacitance of a parallel Plate capacitor increases from $20\mu\text{F}$ to $100\mu\text{F}$ when a dielectric is filled between the plates. The dielectric constant of dielectric is

- a) 65 b) 55 c) 12 **d) 5**

Solution:

$$C_m = C \times \epsilon_r \rightarrow \epsilon_r = \frac{C_m}{C} = \frac{100}{20} = 5$$

47. The magnitude of the force acting on a charge of 2×10^{-10} C placed in a uniform electric field of 10Vm^{-1} is

- a) 2×10^{-9} N b) 4×10^{-9} N c) 2×10^{-10} N d) 4×10^{-10} N

Solution:

$$F = qE = 2 \times 10^{-10} \times 10 = 2 \times 10^{-9}$$

48. Electric potential energy (U) of two point charges is

- a) $q_1q_2 / 4\pi \epsilon_0 r^2$ b) $q_1q_2 / 4\pi \epsilon_0 r$ c) $pE \cos\theta$ d) $pE \sin\theta$

49. The capacitance of a parallel plate capacitor increases from $5 \mu\text{F}$ to $50 \mu\text{F}$ when a dielectric is filled between the plates. The permittivity of the dielectric is

- a) $8.854 \times 10^{-12} \text{ C}^2\text{N}^{-1}\text{m}^{-2}$ b) $8.854 \times 10^{-11} \text{ C}^2\text{N}^{-1}\text{m}^{-2}$
c) 12 d) 10

Solution:

$$\epsilon = \epsilon_0 \epsilon_r = \epsilon_0 \frac{C_m}{C} = 8.854 \times 10^{-12} \times \frac{50}{5} = 8.854 \times 10^{-11}$$

50. The negative gradient of potential is

- a) electric force b) torque c) electric current d) electric field

Solution: $E = -\frac{dV}{dx}$

51. When a point charge of $6\mu\text{C}$ is moved between two points in an electric field, the work done is 1.8×10^{-5} J. The potential difference between the two points is

- a) 1.08 V b) 1.08 mV c) 3V d) 30 V

Solution:

$$V = \frac{W}{q} = \frac{1.8 \times 10^{-5}}{6 \times 10^{-6}} = 3V$$

52. The electric field intensity at a distance r due to infinitely long straight charged wire is directly proportional to

- a) r b) $1/r$ c) r^2 d) $1/r^2$

Solution: $E = \frac{\lambda}{2\pi\epsilon_0 r}$

53. The ratio of electric potential at points 10 cm and 20 cm from the centre of an electric dipole along its axial line is

- a) 1 : 2 b) 2 : 1 c) 1 : 4 d) 4 : 1

Solution:

$$V = \frac{p \cos \theta}{4\pi\epsilon_0 r^2}, \frac{V_1}{V_2} = \frac{r_2^2}{r_1^2} = \frac{20^2}{10^2} = 4:1$$

54. The intensity of the electric field that produces a force of 10^{-5} N on a charge of $5\mu\text{C}$ is

- a) $5 \times 10^{-11} \text{ NC}^{-1}$ b) 50 NC^{-1} **c) 2 NC^{-1}** d) 0.5 NC^{-1}

Solution: $E = \frac{F}{q} = \frac{10^{-5}}{5 \times 10^{-6}} = 2$

55. The unit of the number of electric lines of force passing through a given area is

- a) no unit b) NC^{-1} **c) Nm^2C^{-1}** d) Nm

56. When a point charge of $6\mu\text{C}$ is moved between two points in an equipotential surface. The amount of work done is

- a) 1.08 J b) 1.08 mJ **c) 0J** d) 30 V

57. The work done in rotating the dipole through an angle of 90° is :

- a) zero b) $-\text{PE}$ **c) PE** d) 2PE

Solution: Work done = $\text{PE}(1 - \cos \theta)$ $\theta = 90^\circ$ $w = \text{PE}$

Short Answers - Book Back

1. What is meant by Quantisation of charges?

- ✓ The charge q on any object is equal to an **integral multiple** of **unit of charge e** .
- ✓ **$q = ne$** , where n is any integer. This is called quantisation of electric charge.

2. Write down coulomb's law in vector form & mention what each term represents

According to Coulomb, the force on the point charge q_1 exerted by another point charge q_2 is $\vec{F}_{12} = k \frac{q_1 q_2}{r^2} \hat{r}_{21}$

$\hat{r}_{21}$ - the unit vector directed from charge q_2 to charge q_1

r - the distance between charges, k - proportionality constant

3. What are the difference between Coulomb force and gravitational force?

Gravitational force	Coulomb force (Electrostatic)
Force between two masses is always attractive	Force between two charges can be attractive or repulsive , depending on the nature of charges
Force between two masses is independent of nature of the medium	Force between the two charges depends on nature of the medium

4. Write a short note on superposition principle

The total force acting on a given charge is equal to the **vector sum of forces** exerted on it by all the other charges.

$$\vec{F}_1^{\text{tot}} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} \dots \vec{F}_{1n}$$

5. Define ‘Electric Field’

The electric field at the point P at a distance r from the point charge q is the **force experienced by a unit charge**.

$$\vec{E} = \frac{\vec{F}}{q_0} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

6. What is meant by Electric field lines

Electric field vector forms a set of continuous lines which represent the electric field in some region of space.

7. The electric field never intersect. Justify

- ✓ If some charge placed in intersection point of electric field, then it has to move in two different directions at the same time, which is physically impossible.
- ✓ Hence Electric field lines do not intersect.

8. Define electric dipole. Give the expression for the magnitude of its electric dipole moment and its direction

- ✓ Two equal and opposite charges separated by a small distance constitute an electric dipole. Formula for dipole moment $p = 2qa$
- ✓ **Direction of dipole moment** is from -q to +q

9. Write the general definition of electric dipole moment for a collection of point charge

It is product of any one of **charges of dipole and distance**(2d) between them.

$$\vec{p} = \sum_{i=1}^n q_i \vec{r}_i$$

10. Define electrostatic potential (Or) electric potential

- ✓ The electric potential at a point P is equal to the work done by an external force to bring a unit positive charge with constant velocity from infinity to the point P in the region of the external electric field $\vec{E}$. **Unit:** V or JC^{-1}

11. What is an equipotential surface?

An equipotential surface is a surface on which all the **points are at the same potential**.

12. What are the Properties of equipotential surfaces

- (i) **The work done** to move a charge q between any two points A and B is **zero**.
- (ii) The **electric field is normal** to an equipotential surface.

13. Give the relation between Electric field and electric potential

- ✓ To move a unit positive charge by a small distance dx towards q in the electric field E , the work done is given by $dW = -E dx \rightarrow dV = -E dx$
- ✓ $E = -\frac{dV}{dx}$ **which means** electric field is negative gradient of electric potential.

14. Define ‘electrostatic potential energy’

It is defined as work done in bringing the various charges to their respective positions from infinitely large mutual separation.

15. Define Electric Flux

- ✓ The **number of electric field lines crossing** a given area kept normal to the electric field lines is called electric flux.
- ✓ $\Phi_E = EA \cos\theta$

16. What is meant by electrostatic energy density?

- ✓ The **energy stored per unit volume** of space is defined as energy density.
- ✓ $u_E = \frac{U}{\text{VOLUME}} = \frac{1}{2} \epsilon_0 E^2$

17. Write a short note on electrostatic shielding

- ✓ Consider a cavity inside the conductor. Whatever the charges at the surfaces and whatever the electrical disturbances outside, the electric field inside the cavity is zero.
- ✓ It is the process of shielding a particular region or space from the effect of external field produced by an electric charge.

18. What is polarization?

- ✓ Polarisation is defined as the **total dipole moment per unit volume** of the dielectric.
- ✓ $\vec{p} = \chi_e \vec{E}_{\text{ext}}$

19.What is dielectric strength?

The maximum **electric field** the dielectric can **withstand** before it breakdowns is called dielectric strength.

20.Define ‘capacitance’. Give its unit

- ✓ It is defined as the ratio of the magnitude of charge on either of the conductor plates to the potential difference existing between the conductors.
- ✓ $C = \frac{Q}{V}$ **Unit:** farad (F)

21.What is corona discharge or action of points?

When the electric field near the edge is very high and it ionizes the surrounding air. The positive ions are repelled at the sharp edge and negative ions are attracted towards the sharper edge. This reduces the total charge of the conductor near the sharp edge. This is called action at points or corona discharge.

(OR)

Leakage of charges from the sharp pointed conductor is called corona discharge.

Short Answers - Book Inside

1.State Coulomb’s law

It states that the electrostatic force between two point charges is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

2. What is dielectric?

A dielectric is a **non-conducting material** and has no free electrons. The electrons in a dielectric are bound within the atoms. **Examples:** Ebonite, glass and mica

3. Define electrostatic induction

Charging without actual contact of charged body is called electrostatic induction.

4. What is dielectric breakdown?

When the external electric field applied to a dielectric is very large, it tears the atoms apart so that the bound charges become free charges. Then the dielectric starts to conduct electricity. This is called dielectric breakdown.

5. Write down the difference between polar and non polar molecule

Non polar molecule	Polar molecule
centres of positive and negative charges coincide.	centres of the positive and negative charges are separated
It has no permanent dipole moment	It has a permanent dipole moment.
Examples: Hydrogen (H ₂), oxygen (O ₂),	Examples: H ₂ O, HCl,

6. State the application of corona discharge

(i) Lightning arrester (ii) Van de Graff generator

7. What is electric susceptibility?

✓ It is defined as polarization per unit electric field. $\chi_e = \frac{P}{E}$

8. What are two kinds of electric field?

Uniform electric field will have the same direction and constant magnitude at all points in space.

Non-uniform electric field will have different directions or different magnitudes or both at different points in space.

9. Define one coulomb

One coulomb is a quantity of charge which when placed at a distance of one metre in air from equal and opposite charge experiences a repulsive force of 9×10^9 .

$$r = 1\text{m}, F = 9 \times 10^9\text{N}, q_1 = q_2 = 1\text{C}$$

10. Define Gauss's law

Gauss's law states that if a charge Q is enclosed by an arbitrary closed surface, then the total electric flux Φ_E through the closed surface is

$$\Phi_E = \frac{Q_{\text{encl}}}{\epsilon_0}$$

11. What is called triboelectric charging?

Charging the objects through rubbing is called triboelectric charging.

12. Give reason to support water acts as good solvent.

- ✓ When common salt (NaCl) is taken in water, the electrostatic force between Na and Cl ions is reduced due to high relative permittivity of water.
- ✓ This is the reason water acts as good solvent.

14. Why it is always safer to sit inside a bus than in open ground or under a tree?

- ✓ The metal body of the bus provides electrostatic shielding, since the electric field inside is zero.
- ✓ During lightning, the charges flow through the body of the conductor to the ground with no effect on the person inside that bus.

Long Answers - Book back

1. Discuss the basic properties of electric charges.

(i) Electric charge

- ✓ Electric charge is **intrinsic and fundamental** property of particles.
- ✓ The SI unit of charge is coulomb.

(ii) Conservation of charges

- ✓ The **total electric charge** in the universe is **constant** and charge can neither be created nor be destroyed.
- ✓ Net change in charge will always be zero.

(iii) Quantisation of charges

- ✓ The charge q on any object is equal to an integral multiple of this fundamental unit of charge e .
- ✓ $q = ne$, where n is any integer.

2. Explain in detail about Coulomb's law & its various aspects

It states that the electrostatic force is directly proportional to the product of the magnitude of the two point charges and is inversely proportional to the square of the distance between the two point charges.

$$F \propto \frac{q_1 q_2}{r^2}$$

The direction of forces is along the line joining two charges.

$$F = k \frac{q_1 q_2}{r^2}, \text{ where } k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ Nm}^2\text{C}^{-2}$$

- ✓ One coulomb is defined as quantity of charges which when placed at a distance of 1m in air or vacuum from an equal and similar charge experiences a repulsive force of 9×10^9 in vacuum.
- ✓ In medium of permittivity: $F_m = \frac{1}{4\pi\epsilon} \frac{q_1 q_2}{r^2}$ $\epsilon > \epsilon_0$,
- ✓ Force between two point charges in a medium other than vacuum is always less than that in vacuum.
- ✓ Force between two charges can be attractive or repulsive, depending on the nature of charges.
- ✓ Force between the two charges depends on nature of the medium.
- ✓ Force between the two point charges will change with respect to motion.
- ✓ Coulomb force is always greater than gravitational force.

3. Define Electric field and its various aspect

- ✓ The charge q creates an electric field in the surrounding space.
- ✓ The electric field at the point P at a distance r from the point charge q is the force experienced by a unit charge
- ✓ $\vec{E} = \frac{\vec{F}}{q_0} = \frac{kq}{r^2} \hat{r}$

Important aspects of Electric field

- ✓ If charge q is positive -electric field points away from the source charge. If q is negative - electric field points towards the source charge q .
- ✓ Force experienced by test charge placed at point P is Eq_0 .
- ✓ Electric field depends only on the source charge q & independent on charge q_0 .
- ✓ The electric field is a vector quantity, at every point in space, this field has unique direction and magnitude.
- ✓ Distance r decreases, Electric field Increases.
- ✓ Two kinds of the electric field are uniform (constant) electric field and non-uniform electric field.

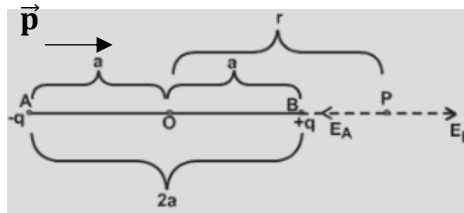
Uniform electric field - same direction and constant magnitude at all points in space.

Non-uniform electric field - different directions or different magnitudes or both at different points in space.

4. Calculate the electric field due to a dipole on axial and equatorial plane.

Electric field due to an electric dipole on the axial line

- ✓ Consider an electric dipole placed on x axis.
- ✓ A point C is located at a distance of r from the midpoint O of the dipole along the axial line.



The electric field at a point C due to +q

$$\vec{E}_B = \frac{1}{4\pi\epsilon_0} \frac{q}{(r-a)^2} \hat{p} \dots\dots\dots(1)$$

The electric field at a point C due to -q

$$\vec{E}_A = -\frac{1}{4\pi\epsilon_0} \frac{q}{(r+a)^2} \hat{p} \dots\dots\dots(2)$$

Total electric fields at C calculated using super position principle

$\begin{aligned} \vec{E}_{\text{tot}} &= \vec{E}_B + \vec{E}_A \\ &= \frac{1}{4\pi\epsilon_0} \frac{q}{(r-a)^2} \hat{p} - \frac{1}{4\pi\epsilon_0} \frac{q}{(r+a)^2} \hat{p} \\ &= \frac{q}{4\pi\epsilon_0} \left(\frac{1}{(r-a)^2} - \frac{1}{(r+a)^2} \right) \hat{p} \\ &= \frac{q}{4\pi\epsilon_0} \left(\frac{4ra}{(r^2-a^2)^2} \right) \hat{p} \end{aligned}$	$\begin{aligned} r &\gg a, (r^2 - a^2)^2 = r^4 \\ &= \frac{q}{4\pi\epsilon_0} \left(\frac{4ra}{r^4} \right) \hat{p} \\ \vec{E}_{\text{tot}} &= \frac{1}{4\pi\epsilon_0} \left(\frac{4aq}{r^3} \right) \hat{p} \\ &= \frac{1}{4\pi\epsilon_0} \left(\frac{2\vec{p}}{r^3} \right) \text{ since } 2aq\hat{p} = \vec{p} \end{aligned}$
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The direction of electric field is along the direction of the dipole moment.

Electric field due to an electric dipole on the equatorial plane

- ✓ Consider point C is located at a distance of r from the midpoint O of the dipole on equatorial plane. C is equidistant from +q & -q, the magnitude of electric field of +q & -q are the same.
- ✓ Direction of $\vec{E}_+$ along BC & Direction of $\vec{E}_-$ along CA.
- ✓ $\vec{E}_+$ & $\vec{E}_-$ resolved into two components which are parallel and perpendicular components.

- ✓ Perpendicular components $|\vec{E}_+|\sin\theta$ & $|\vec{E}_-|\sin\theta$ are oppositely directed so cancel each other.
- ✓ Parallel components $|\vec{E}_+|\cos\theta$ & $|\vec{E}_-|\cos\theta$ are in same direction added to get resultant electric field.

$$\vec{E}_{\text{tot}} = -|\vec{E}_+|\cos\theta\hat{p} - |\vec{E}_-|\cos\theta\hat{p}$$

$$|\vec{E}_+| = |\vec{E}_-| = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2 + a^2}$$

$$\vec{E}_{\text{tot}} = -\frac{1}{4\pi\epsilon_0} \frac{q}{r^2 + a^2} \cos\theta - \frac{1}{4\pi\epsilon_0} \frac{q}{r^2 + a^2} \cos\theta$$

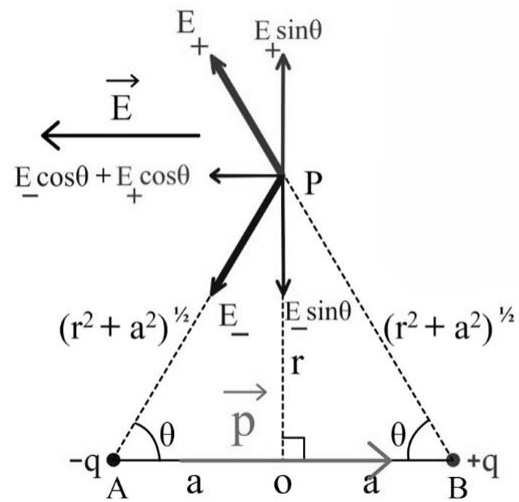
$$\vec{E}_{\text{tot}} = -\frac{1}{4\pi\epsilon_0} \frac{2q \cos\theta}{r^2 + a^2} \hat{p}$$

$$\vec{E}_{\text{tot}} = -\frac{1}{4\pi\epsilon_0} \frac{2qa}{(r^2 + a^2)^{3/2}} \hat{p} \quad \text{since } \cos\theta = \frac{a}{(r^2 + a^2)^{1/2}}$$

$$\vec{E}_{\text{tot}} = -\frac{1}{4\pi\epsilon_0} \frac{\vec{p}}{(r^2 + a^2)^{3/2}} \quad \text{since } 2aq\hat{p} = \vec{p}$$

$$r \gg a, (r^2 + a^2)^{3/2} = r^3$$

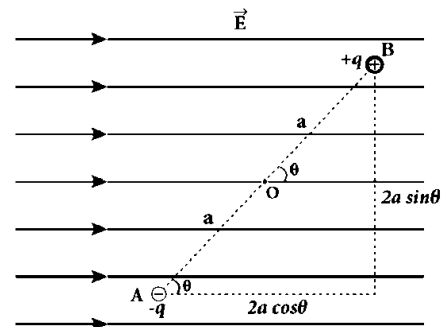
$$\vec{E}_{\text{tot}} = -\frac{1}{4\pi\epsilon_0} \left(\frac{\vec{p}}{r^3} \right)$$



The direction of electric field acts opposite to the direction of the dipole moment

5. Derive an expression for Torque experienced by a dipole due to a uniform electric field

- ✓ Consider an electric dipole of dipole moment $\vec{p}$ placed in a uniform electric field.
- ✓ The charge $+q$ will experience a force $q\vec{E}$ in the direction of the field.
- ✓ charge $-q$ will experience a force $-q\vec{E}$ in a direction opposite to the field.
- ✓ Total force acting on the dipole is zero. These two forces acting at different points will constitute a couple and the dipole experience a torque.
- ✓ This torque tends to rotate the dipole.



$$\text{Torque on the dipole about the point O} \rightarrow \vec{\tau} = \vec{OA} \times (-q\vec{E}) + \vec{OB} \times (q\vec{E})$$

The magnitude of total torque

$$\tau = |\vec{OA}| |-q\vec{E}| \sin\theta + |\vec{OB}| |q\vec{E}| \sin\theta$$

$$= qE 2a \sin\theta \text{ [where } |\vec{OA}| = |\vec{OB}| = a]$$

Torque in vector form: $\vec{\tau} = \vec{p} \times \vec{E}$ (since $p = 2qa$)

6. Derive an expression for electrostatic potential due to point charge.

- ✓ Consider a positive charge q kept fixed at the origin.
- ✓ Let P be a point at distance r from the charge q .

Electric potential at point P

$$V = \int_{\infty}^r (-\vec{E}) \cdot d\vec{r} = - \int_{\infty}^r (\vec{E}) \cdot d\vec{r}$$

$$\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

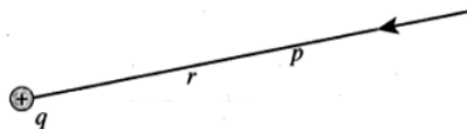
$$V = - \int_{\infty}^r \frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r} \cdot d\vec{r}$$

$$d\vec{r} = dr \hat{r}, \hat{r} \cdot \hat{r} = 1$$

$$V = - \frac{1}{4\pi\epsilon_0} \int_{\infty}^r \frac{q}{r^2} \cdot dr$$

After the integration

$$V = - \frac{1}{4\pi\epsilon_0} q \left[-\frac{1}{r} \right]_{\infty}^r = \frac{1}{4\pi\epsilon_0} \frac{q}{r}$$



7. Derive an expression for electrostatic potential due to an electric dipole.

- ✓ Consider two equal and opposite charges separated by a small distance $2a$.
- ✓ The point P is located at a distance r from the midpoint of the dipole.
- ✓ Let θ be the angle between the line OP and dipole axis AB .

$$\text{Potential at } P \text{ due to charge } +q: V_1 = \frac{1}{4\pi\epsilon_0} \frac{q}{r_1}$$

$$\text{Potential at } P \text{ due to charge } -q: V_2 = - \frac{1}{4\pi\epsilon_0} \frac{q}{r_2}$$

Total potential at the point P

$$V = V_1 + V_2 = \frac{1}{4\pi\epsilon_0} q \left(\frac{1}{r_1} - \frac{1}{r_2} \right) \dots \dots \dots (1)$$

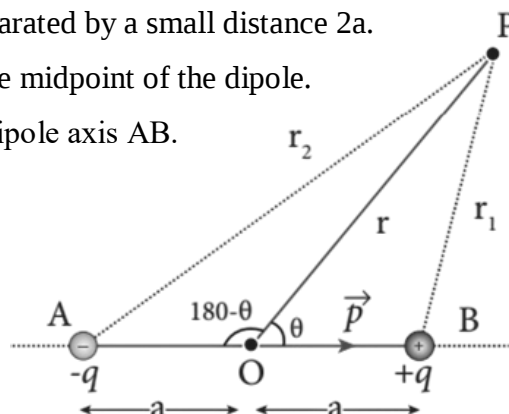
By the cosine law for triangle BOP

$$r_1^2 = r^2 + a^2 - 2ra \cos\theta$$

$$= r^2 \left(1 + \frac{a^2}{r^2} - \frac{2a}{r} \cos\theta \right)$$

$$r \gg a; \frac{a^2}{r^2} \text{ can be neglected}$$

$$r_1^2 = r^2 \left(1 - \frac{2a}{r} \cos\theta \right)$$



$$r_1 = r \left(1 - \frac{2a}{r} \cos\theta \right)^{\frac{1}{2}}$$

$$\frac{1}{r_1} = \frac{1}{r} \left(1 - \frac{2a}{r} \cos\theta \right)^{-\frac{1}{2}}$$

Using binomial theorem

$$\frac{1}{r_1} = \frac{1}{r} \left(1 + \frac{a}{r} \cos\theta \right) \dots \dots \dots (2)$$

Similarly applying the cosine law for triangle AOP,

$$r_2^2 = r^2 + a^2 - 2ra \cos(180 - \theta)$$

$$= r^2 \left(1 + \frac{a^2}{r^2} + \frac{2a}{r} \cos \theta \right)$$

$r \gg a$; $\frac{a^2}{r^2}$ can be neglected

$$\frac{1}{r_2} = \frac{1}{r} \left(1 + \frac{2a}{r} \cos \theta \right)^{-\frac{1}{2}}$$

Using binomial theorem

$$\frac{1}{r_2} = \frac{1}{r} \left(1 - \frac{a}{r} \cos \theta \right) \dots \dots \dots (3)$$

Sub (3) & (2) in (1)

$$V = \frac{1}{4\pi\epsilon_0} q \left[\frac{1}{r} \left(1 + \frac{a}{r} \cos \theta \right) - \frac{1}{r} \left(1 - \frac{a}{r} \cos \theta \right) \right]$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{2aq}{r^2} \cos \theta$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2} \cos \theta \quad (\text{since } p = 2qa)$$

$$V = \frac{1}{4\pi\epsilon_0} \frac{\vec{p} \cdot \hat{r}}{r^2} (r \gg a) \quad (\text{since: } p \cos \theta = \vec{p} \cdot \hat{r})$$

Special cases

Case (i) If the point P lies on the axial line of the dipole on the side of $+q$, then $\theta = 0^\circ$

$$V = \frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$

Case (ii) If the point P lies on the axial line of the dipole on the side of $-q$, then $\theta = 180^\circ$, then

$$V = -\frac{1}{4\pi\epsilon_0} \frac{p}{r^2}$$

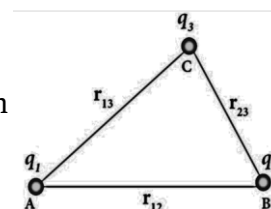
Case (iii) If the point P lies on the equatorial line of the dipole, then $\theta = 90^\circ$. Hence $V = 0$

8. Obtain an expression for potential energy due to collection of three point charges which are separated by finite distances

The electric potential at a point at a distance r from point charge q_1 is given by

$$V = \frac{1}{4\pi\epsilon_0} \frac{q_1}{r}$$

This potential V is the work done to bring a unit positive charge from infinity to the point. Now if the charge q_2 is brought from infinity to that point at a distance r from q_1 , the work done is the product of q_2 and the electric potential at that point.



$$W = q_2 V$$

This work done is stored as the electrostatic potential energy U

$$U = q_2 V = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

Three charges are arranged in the following configuration

i) Bringing a charge q_1 from infinity to the point A requires no work, because there are no other charges already present in the vicinity of charge q_1

ii) To bring the second charge q_2 to the point B, work must be done against the electric field created by the charge q_1 . So the work done on the charge q_2 is $W = q_2 V_{1B}$. Here V_{1B} is the electrostatic potential due to the charge q_1 at point B.

$$U = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r_{12}}$$

iii) Similarly to bring the charge q_3 to the point C, work has to be done against the total electric field due to both charges q_1 and q_2 . So the work done to bring the charge q_3 is $= q_3 (V_{1C} + V_{2C})$. Here V_{1C} is the electrostatic potential due to charge q_1 at point C and V_{2C} is the electrostatic potential due to charge q_2 at point C.

$$U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} \right)$$

iv) Total electrostatic potential energy for the system of charges q_1, q_2, q_3 is

$$U = \frac{1}{4\pi\epsilon_0} \left(\frac{q_1 q_3}{r_{13}} + \frac{q_2 q_3}{r_{23}} + \frac{q_1 q_2}{r_{12}} \right)$$

9. Derive an expression for electrostatic potential energy of the dipole in a uniform electric field.

- ✓ Consider a dipole placed in the uniform electric field $\vec{E}$ which experiences a torque
- ✓ This torque rotates the dipole to align it with the direction of the electric field.
- ✓ To rotate the dipole (at constant angular velocity) from its initial angle θ' to another angle θ against the torque exerted by the electric field, an equal and opposite external torque must be applied on the dipole.

The work done by the external torque to rotate the dipole from angle θ' to θ at constant angular

velocity is $W = \int_{\theta'}^{\theta} \tau_{\text{ext}} d\theta \dots\dots\dots(1)$

$$\tau = pE \sin \theta \dots\dots\dots(2)$$

substituting (2) in (1) in above equation

$$W = \int_{\theta'}^{\theta} pE \sin \theta d\theta$$

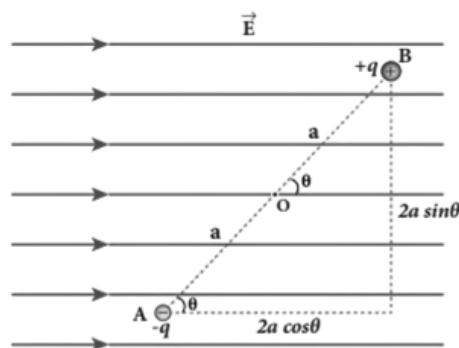
$$W = -pE [\cos \theta]_{\theta'}^{\theta},$$

$$W = pE (\cos \theta' - \cos \theta)$$

$$U(\theta) - U(\theta') = -pE \cos \theta + pE \cos \theta'$$

$$\theta' = 90^\circ, \cos 90^\circ = 0$$

$$U = -pE \cos \theta = -\vec{p} \cdot \vec{E}$$



10. Obtain Gauss law from Coulomb's law

Gauss's law

Gauss's law states that if a charge Q is enclosed by an arbitrary closed surface, then the total electric flux Φ_E through the closed surface is

$$\Phi_E = \frac{Q_{\text{encl}}}{\epsilon_0}$$

$$\Phi_E = \oint \vec{E} \cdot d\vec{A} \cos \theta \dots\dots\dots(1)$$

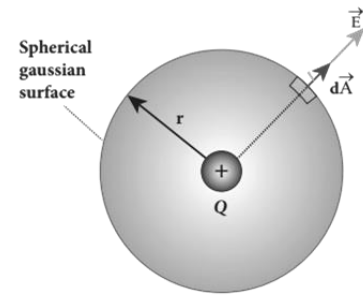
$$\theta = 0^\circ, \cos 0^\circ = 1$$

$$\Phi_E = \oint E \cdot dA \dots\dots\dots(2)$$

$$\Phi_E = E \oint dA \dots\dots\dots(3)$$

$$\text{Sub } \oint dA = 4\pi r^2 \text{ in (3)}$$

$$\text{Therefore } \Phi_E = E \cdot 4\pi r^2$$



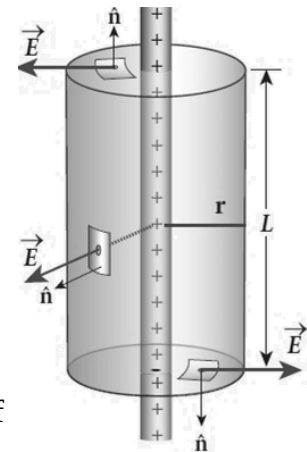
$$\text{Where } E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

$$\Phi_E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2} \times 4\pi r^2$$

$$\Phi_E = \frac{Q}{\epsilon_0}$$

11. Obtain expression for electric field due to an infinitely long charged wire

- ✓ Consider an infinitely long straight wire having uniform linear charge density λ .
- ✓ Let P be a point located at a perpendicular distance r from the wire.
- ✓ Two small charge elements A_1 and A_2 on the wire which are at equal distances from the point P .
- ✓ The resultant electric field due to these two charge elements points radially away from the charged wire and the magnitude of electric field is same at all points on the circle of radius r .
- ✓ Charged wire possesses a cylindrical symmetry of radius r and length L .



$$\Phi_E = \oint \vec{E} \cdot d\vec{A}$$

$$= \int_{\text{curved surface}} \vec{E} \cdot d\vec{A} + \int_{\text{Top surface}} \vec{E} \cdot d\vec{A} + \int_{\text{Bottom surface}} \vec{E} \cdot d\vec{A}$$

$\vec{E}$ and $d\vec{A}$ are right angles to each other.

$$\int_{\text{Top surface}} \vec{E} \cdot d\vec{A} = \int_{\text{Bottom surface}} \vec{E} \cdot d\vec{A} = 0$$

$$\int_{\text{curved surface}} \vec{E} \cdot d\vec{A} = \oint E \cdot dA \cos \theta$$

$$\Phi_E = \oint E \cdot dA \quad [\text{since } \theta = 0, \cos 0 = 1]$$

$$= E(2\pi rL) \dots\dots\dots(1) \quad [\text{since } \oint dA = 2\pi rL]$$

$$\text{By Gauss law: } \Phi_E = \frac{Q}{\epsilon_0} = \frac{\lambda l}{\epsilon_0} \dots\dots\dots(2)$$

Equating (1) & (2)

$$E(2\pi rl) = \frac{\lambda l}{\epsilon_0}$$

$$E = \frac{\lambda}{2\pi\epsilon_0 r}$$

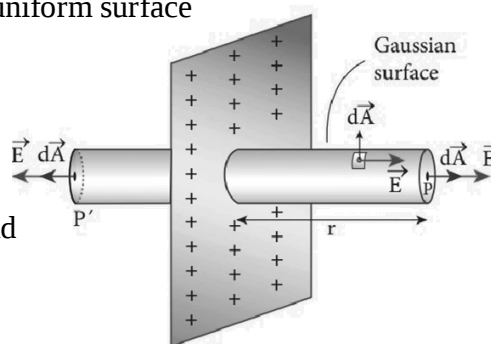
$$E(2\pi rl) = \frac{\lambda l}{\epsilon_0}$$

Direction of electric field is radially outward if line charge is positive and inward if the line charge is negative.

In vector form: $\vec{E} = \frac{\lambda}{2\pi\epsilon_0 r} \vec{r}$

12. Obtain expression for electric field due to a charged infinitely plane sheet.

- ✓ Consider an infinite plane sheet of charges with uniform surface charge density σ .
- ✓ Let P be a point at a distance of r from the sheet.
- ✓ Since the plane is infinitely large, the electric field should be same at all points equidistant from the plane and radially directed at all points.
- ✓ A cylindrical shaped Gaussian surface of length 2r and area A of the flat surfaces is chosen such that the infinite plane sheet passes perpendicularly through the middle part of the Gaussian surface.



$$\phi_E = \int_{\text{curved surface}} \vec{E} \cdot d\vec{A} + \int_P \vec{E} \cdot d\vec{A} + \int_{P'} \vec{E} \cdot d\vec{A}$$

$$\phi_E = \frac{Q_{\text{encl}}}{\epsilon_0}$$

The electric field is perpendicular to the area element at all points on the curved

surface so $\int_{\text{curved surface}} \vec{E} \cdot d\vec{A} = 0$

$$\phi_E = \int_P \vec{E} \cdot d\vec{A} + \int_{P'} \vec{E} \cdot d\vec{A} = \frac{Q_{\text{encl}}}{\epsilon_0}$$

Magnitude of the electric field at these two equal surfaces is uniform.

$$2E \int dA = \frac{Q_{\text{encl}}}{\epsilon_0} = \frac{\sigma A}{\epsilon_0} \text{ [since } Q_{\text{encl}} = \sigma A \text{]}$$

$$2EA = \frac{\sigma A}{\epsilon_0} \text{ [Since } \int dA = A \text{]}$$

$$E = \frac{\sigma}{2\epsilon_0}$$

In vector Form: $\vec{E} = \frac{\sigma}{2\epsilon_0} \hat{n}$

13. Obtain expression for electric field due to uniformly charged spherical shell

Consider a uniformly charged spherical shell of radius R and total charge Q. The electric field at points outside and inside the sphere is found using Gauss law.

Case (a) At a point outside the shell ($r > R$)

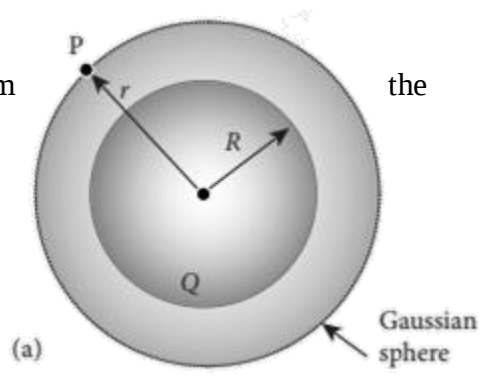
- ✓ Consider a point P outside the shell at a distance r from the center.
- ✓ Consider a spherical Gaussian surface of radius r is chosen and the total charge enclosed by this Gaussian surface is Q .

Applying Gauss law

$$\oint_{\text{Gaussian Surface}} \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$$

Magnitude of $\vec{E}$ is the same at all points due to the spherical symmetry of the charge distribution.

$$E \oint_{\text{Gaussian Surface}} dA = \frac{Q}{\epsilon_0}$$



$$\oint_{\text{Gaussian Surface}} dA = 4\pi r^2$$

$$E \cdot 4\pi r^2 = \frac{Q}{\epsilon_0}$$

$$E = \frac{1}{4\pi\epsilon_0} \frac{Q}{r^2}$$

Case (b): At a point on the surface of the spherical shell ($r = R$)

The electric field at a point on the spherical shell ($r = R$) is given by $\vec{E} = \frac{1}{4\pi\epsilon_0} \frac{Q}{R^2} \hat{r}$

Case(c): At a point inside the spherical shell ($r < R$)

Consider a point P inside the shell at a distance r from the center.

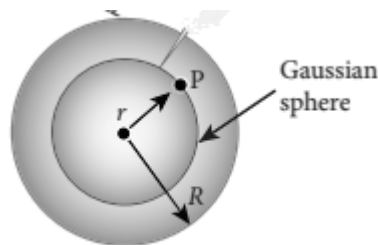
Applying Gauss law

$$\oint \vec{E} \cdot d\vec{A} = \frac{Q}{\epsilon_0}$$

$$E \cdot 4\pi r^2 = \frac{Q}{\epsilon_0}$$

Gaussian surface encloses no charge, So $Q = 0$.

Hence $E = 0$



14. Discuss the various properties of conductors in electrostatic equilibrium

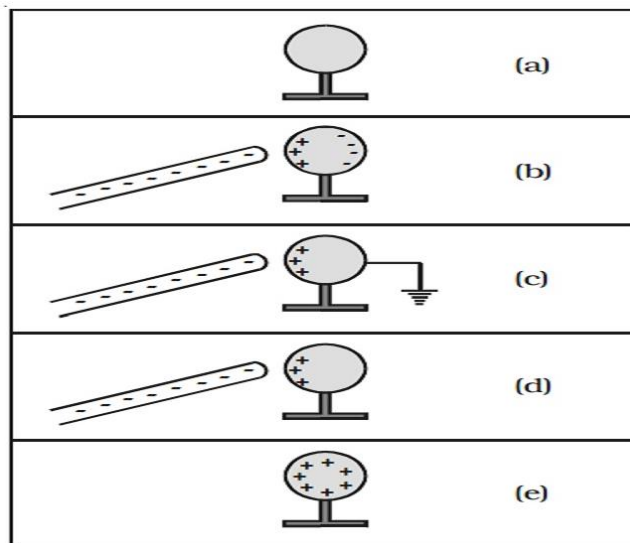
- ✓ The **electric field is zero** everywhere inside the conductor.
- ✓ There is **no net charge inside** the conductors. The charges must reside only on the surface of the conductors.
- ✓ The electric field outside the conductor is perpendicular to the surface of the conductor and has a magnitude of $\frac{\sigma}{\epsilon_0}$.

- ✓ The electrostatic potential has the same value on the surface and inside of the conductor.
- ✓ At electrostatic equilibrium, the conductor is always at equipotential.

15.Explain the process of electrostatic induction.

Charging without actual contact of charged surface is called electrostatic induction.

a) Consider an uncharged (neutral) conducting sphere at rest on an insulating stand. Suppose a negatively charged rod is brought near the conductor without touching it. The negative charge of the rod repels the electrons in the conductor to the opposite side. As a result, positive charges are induced near



the region of the charged rod while negative charges on the farther side. Once the charged rod is brought near the conductor, the distribution is no longer uniform with more electrons located on the farther side of the rod and positive charges are located closer to the rod. But the total charge is zero.

b) Now the conducting sphere is connected to the ground through a conducting wire. This is called grounding.

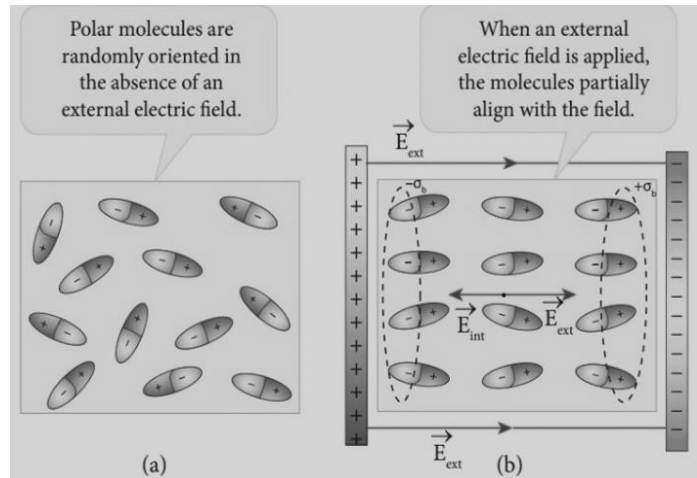
c) When the grounding wire is removed from the conductor, the positive charges remain near the charged rod

d) Now the charged rod is taken away from the conductor. As soon as the charged rod is removed, the positive charge gets distributed uniformly on the surface of the conductor. By this process, the neutral conducting sphere becomes positively charged.

16.Explain dielectric in detail and how an electric field is induced inside a dielectric.

- ✓ In dielectric, which has no free electrons, when the external electric field is applied, the field only realigns the charges so that an internal electric field is produced.
- ✓ The magnitude of the internal electric field is smaller than that of external electric

- ✓ field. Therefore the net electric field inside the dielectric is not zero but is parallel to an external electric field with magnitude less than that of the external electric field.
- ✓ Let us consider a rectangular dielectric slab placed between two oppositely charged plates (capacitor)
- ✓ The uniform electric field between the plates acts as an external electric field which polarizes the dielectric placed between plates. The positive charges are induced on one side surface and negative charges are induced on the other side of surface.
- ✓ But inside the dielectric, the net charge is zero even in a small volume. So the dielectric in the external field is equivalent to two oppositely charged sheets with the surface charge densities $+\sigma_b$ and $-\sigma_b$. These charges are called bound charges. They are not free to move like free electrons in conductors.



17. Obtain the expression for capacitance for a parallel plate capacitor

Consider a capacitor with two parallel plates each of cross-sectional area A and separated by a distance d .

The electric field between two infinite parallel plates is uniform and is given by

$$E = \frac{\sigma}{\epsilon_0} \dots\dots\dots(1) \quad \sigma = \frac{Q}{A}$$

The electric field between the plates is

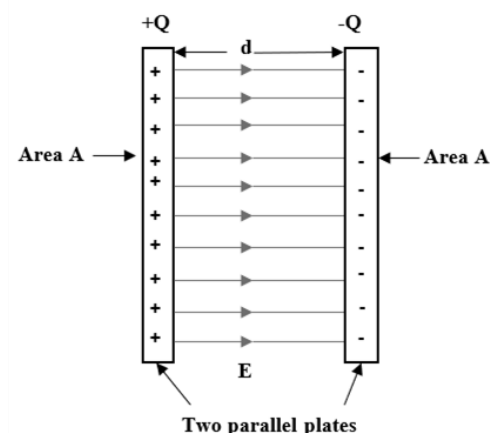
$$E = \frac{Q}{A\epsilon_0} \dots\dots\dots(2)$$

$$V = Ed = \frac{Qd}{A\epsilon_0} \dots\dots\dots(3)$$

Capacitance of the capacitor is given by

$$C = \frac{Q}{V} = \frac{Q}{\frac{Qd}{A\epsilon_0}} = \frac{\epsilon_0 A}{d}$$

$$C \propto A \quad C \propto \frac{1}{d}$$



18. Obtain the expression for energy stored in the parallel plate capacitor

- ✓ Capacitor not only stores the charge but also it stores energy.

- ✓ When a battery is connected to the capacitor, electrons of total charge $-Q$ are transferred from one plate to the other plate.
- ✓ To transfer the charge, work is done by the battery.
- ✓ This work done is stored as electrostatic potential energy in the capacitor.
- ✓ To transfer an infinitesimal charge dQ for a potential difference V , the work done is given by

$$dW = V dQ$$

$$V = \frac{Q}{C}$$

The total work done to charge a capacitor is

$$W = \int_0^Q \frac{Q}{C} dQ = \frac{Q^2}{2C}$$

This work done is stored as electrostatic potential energy (U_E) in the capacitor

$$U_E = \frac{Q^2}{2C} = \frac{1}{2} CV^2$$

$$U_E \propto C,$$

$$U_E \propto V^2$$

19. Explain in detail effect of a dielectric placed in parallel plate capacitor

The dielectric can be inserted into the plates in two different ways.

- when the capacitor is disconnected from the battery.
- when the capacitor is connected to the battery.

(i) When the capacitor is disconnected from the battery

- ✓ Consider a capacitor with two parallel plates each of cross-sectional area A and are separated by a distance d .
- ✓ The capacitor is charged by a battery of voltage V_0 and the charge stored is Q_0 .
- ✓ capacitance of the capacitor without the dielectric is $C_0 = \frac{Q_0}{V_0}$
- ✓ The battery is then disconnected from the capacitor and the dielectric is inserted between the plates
- ✓ The introduction of dielectric between the plates will decrease the electric field.

$$E = \frac{E_0}{\epsilon_r}$$

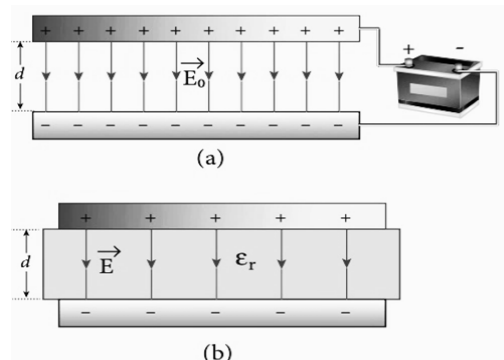
$\epsilon_r > 1$, the electric field $E < E_0$.

$$V = Ed = \frac{E_0 d}{\epsilon_r} = \frac{V_0}{\epsilon_r}$$

Thus new capacitance in the presence of a dielectric is

$$C = \frac{Q_0}{V} = \epsilon_r \frac{Q_0}{V_0} = \epsilon_r C_0$$

$\epsilon_r > 1$, we have $C > C_0$.



Thus insertion of the dielectric constant ϵ_r increases the capacitance.

The energy stored in the capacitor before the insertion of a dielectric is given by

$$U_0 = \frac{Q_0^2}{2C_0}$$

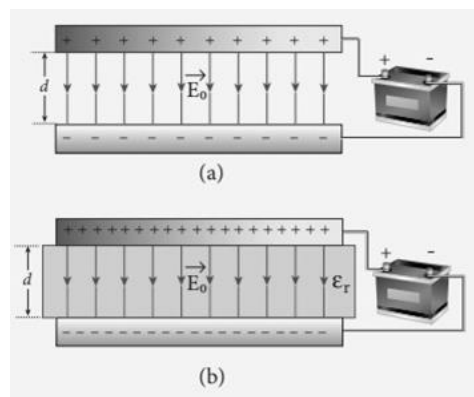
After the dielectric is inserted,

$$U = \frac{Q_0^2}{2C} = \frac{Q_0^2}{2\epsilon_r C_0} = \frac{U_0}{\epsilon_r}$$

There is a decrease in energy because, when the dielectric is inserted,

ii) When the battery remains connected to the capacitor

- ✓ Consider battery of voltage V_0 remains connected to the capacitor when the dielectric is inserted into the capacitor
- ✓ The potential difference V_0 across the plates remains constant.
- ✓ When dielectric is inserted, the charge stored in the capacitor is increased by a factor ϵ_r .



$$Q = \epsilon_r Q_0$$

Due to this increased charge, the capacitance is also increased. The new capacitance is

$$C = \frac{Q}{V} = \epsilon_r \frac{Q_0}{V_0} = \epsilon_r C_0$$

$$C_0 = \frac{\epsilon_0 A}{d}$$

$$C = \frac{\epsilon A}{d}$$

The energy stored in the capacitor before the insertion of a dielectric is given by

$$U_0 = \frac{1}{2} C_0 V_0^2$$

After the dielectric is inserted, the capacitance is increased; hence the stored energy is also increased.

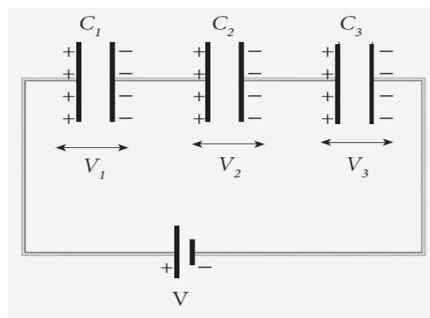
$$U = \frac{1}{2} C V_0^2 = \frac{1}{2} \epsilon_r C V_0^2 = \epsilon_r U_0$$

Since $\epsilon_r > 1$ we have $U > U_0$

20. Derive the expression for resultant capacitance when capacitors are connected in series and in parallel.

Capacitance in series

- ✓ C_1 , C_2 and C_3 connected in series.
- ✓ C_s is effective capacitance
- ✓ Charge in each capacitor is same
- ✓ Voltage across each capacitor is different



$$V = V_1 + V_2 + V_3$$

$$V = \frac{q}{C_s}, V_1 = \frac{q}{C_1}, V_2 = \frac{q}{C_2}, V_3 = \frac{q}{C_3}$$

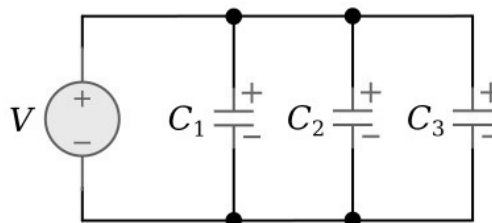
$$\frac{q}{C_s} = \frac{q}{C_1} + \frac{q}{C_2} + \frac{q}{C_3}$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

The inverse of the equivalent capacitance C_s of three capacitors connected in series is equal to the sum of the inverses of each capacitance.

Capacitance in parallel

- ✓ C_1 , C_2 and C_3 connected in Parallel.
- ✓ C_p is effective capacitance.
- ✓ Potential in each capacitor is same & Charge in each capacitor is different.



$$q_1 = C_1 V, q_2 = C_2 V, q_3 = C_3 V, q = C_p V$$

$$C_p V = C_1 V + C_2 V + C_3 V$$

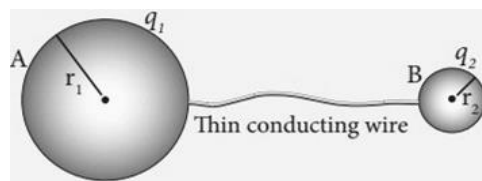
$$C_p = C_1 + C_2 + C_3$$

The equivalent capacitance of capacitors connected in parallel is equal to the sum of the individual capacitances.

21. Explain in detail how charges are distributed in a conductor & the principle behind lightning conductor

Consider two conducting spheres A and B of radii r_1 and r_2 respectively connected to each other by a thin conducting wire. The distance between the spheres is much greater than the radii of either spheres.

If a charge Q is introduced into any one of the spheres, this charge Q is redistributed into both the spheres such that the electrostatic potential is



same in both the spheres. They are now uniformly charged and attain electrostatic equilibrium.

Let q_1 be the charge residing on the surface of sphere A and q_2 is the charge residing on the surface of sphere B such that $Q = q_1 + q_2$. The charges are distributed only on the surface and there is no net charge inside the conductor.

The electrostatic potential at the surface of the sphere A is given by

$$V_A = \frac{1}{4\pi\epsilon_0} \frac{q_1}{r_1}$$

The electrostatic potential at the surface of the sphere B is given by

$$V_B = \frac{1}{4\pi\epsilon_0} \frac{q_2}{r_2}$$

Surfaces of both the spheres together form an equipotential surface. This implies that

$$V_A = V_B$$

$$\frac{q_1}{r_1} = \frac{q_2}{r_2}$$

This implies that $q_1 = 4\pi r_1^2 \sigma_1$ and $q_2 = 4\pi r_2^2 \sigma_2$

$$\sigma r = \text{constant}$$

Thus the surface charge density σ is inversely proportional to the radius of the sphere. For a smaller radius, the charge density will be larger and vice versa

Principle behind lightning conductor

- ✓ Lightning conductor is a device used to protect tall buildings from lightning strikes. It works on the principle of action at points or corona discharge.
- ✓ The leakage of charges from sharp pointed conductor is called corona discharge

22.Explain in detail the construction and working of a van de Graff generator.

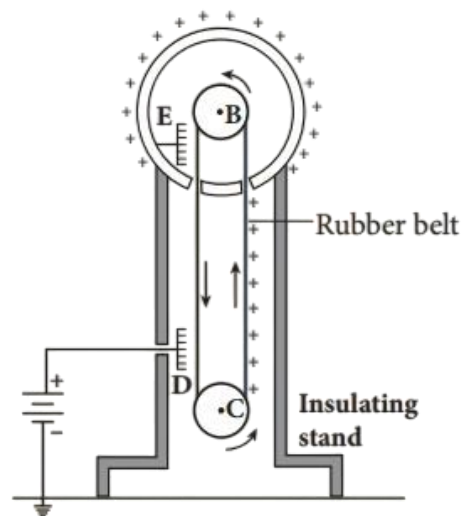
It is a machine which produces a large amount of electrostatic potential difference, up to several million volts (10^7 V).

Principle

Electrostatic induction and action at points.

Construction

- 1) A large hollow spherical conductor is fixed on the insulating stand.
- 2) Pulley B is mounted at the center of the hollow sphere
- 3) Pulley C is fixed at the bottom.
- 4) A belt made up of insulating materials like silk or rubber runs over both pulleys.
- 5) The pulley C is driven continuously by the electric motor.
- 6) Two comb shaped metallic conductors E and D are fixed near the pulleys.
- 7) The comb D is maintained at a positive potential of 10^4 V by a power supply.
- 8) The upper comb E is connected to the inner side of the hollow metal sphere.



Working

(i) Action of points

- 1) Due to the high electric field near comb D, air between the belt and comb D gets ionized. The positive charges are pushed towards the belt and negative charges are attracted towards the comb D.
- 2) The positive charges stick to the belt and move up.

(ii) Electrostatic induction

- 1) When the positive charges reach the comb E, a large amount of negative and positive charges are induced on either side of comb E due to electrostatic induction.
- 2) As a result, the positive charges are pushed away from the comb E and they reach the outer surface of the sphere.
- 3) At the same time, the negative charges nullify the positive charges in the belt due to corona discharge before it passes over the pulley.
- 4) When the belt descends, it has almost no net charge.
- 5) This process continues until the outer surface produces the potential difference of the order of 10^7 which is the limiting value.

Leakage and prevention

- 1) The leakage of charges can be reduced by enclosing the machine in a gas filled steel chamber at very high pressure.

Uses

It is used to accelerate positive ions (protons and deuterons) for nuclear disintegrations and other applications.

Long Answers - Book Inside

1. Explain the properties of electric field lines

- ✓ The electric field lines start from a positive charge and end at negative charges or at infinity.
- ✓ The electric field vector at a point in space is tangential to the electric field line at that point.
- ✓ The electric field lines are denser (more closer) in a region where the electric field has larger magnitude and less dense in a region where the electric field is of smaller magnitude.
- ✓ No two electric field lines intersect each other.
- ✓ The number of electric field lines is directly proportional to the magnitude of the charges.

2. Give the applications of capacitors

- ✓ Digital camera to emit flashlight
- ✓ Heart defibrillator to retrieve the normal heart function
- ✓ ignition system of automobile engines to eliminate sparking
- ✓ To reduce power fluctuations in power supplies and to increase the efficiency of power transmission.

3. Derive the expression for electric field due to two long parallel charged infinite sheets.

- ✓ Consider two infinitely large charged plane sheets with equal and opposite charge densities $+\sigma$ and $-\sigma$ which are placed parallel to each other.
- ✓ The magnitude of the electric field due to an infinite charged plane sheet is $\frac{\sigma}{2\epsilon_0}$

Outside the plates

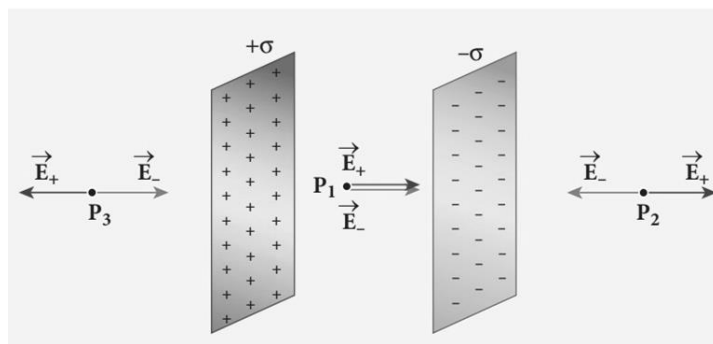
- ✓ At the points P_2 and P_3 , the electric field due to both plates are equal in magnitude and opposite in direction.
- ✓ As a result, electric field at a point outside the plates is zero.

Inside the plates

- ✓ Inside the plate electric fields are in same direction

$$E_{\text{inside}} = \frac{\sigma}{2\epsilon_0} + \frac{\sigma}{2\epsilon_0} = \frac{\sigma}{\epsilon_0}$$

- ✓ The direction of the electric field inside the plates is directed from positively charged plate to negatively charged plate and is uniform everywhere inside the plate.



3.Explain the working of microwave oven

- ✓ Microwave oven works on the **principle of torque acting on an electric dipole**.
- ✓ The food we consume has water molecules which are permanent electric dipoles.
- ✓ Oven produces microwaves that are oscillating electromagnetic fields and produce torque on the water molecules.
- ✓ Due to this torque on each water molecule, the molecules rotate very fast and produce thermal energy.
- ✓ Thus, heat generated is used to heat the food.

Numerical Problems Solved

1. When two objects are rubbed with each other, approximately a charge of 50 nC can be produced in each object. Calculate the number of electrons that must be transferred to produce this charge.

Given

$$q = 50 \text{ nC} = 50 \times 10^{-9} \text{ C} \quad e^- = 1.6 \times 10^{-19} \text{ C}$$

To find : n

Solution

$$n = \frac{q}{e} = \frac{50 \times 10^{-9}}{1.6 \times 10^{-19}}$$

$$n = \frac{50 \times 10^{10}}{1.6} = \frac{25 \times 10^{10}}{8 \times 10^{-1}}$$

$$n = 3.125 \times 10^{11} \text{ electrons}$$

2. The total number of electrons in the human body is typically in the order of 10^{28} . Suppose, due to some reason, you and your friend lost 1% of this number of electrons. Calculate the electrostatic force between you and your friend separated at a distance of

1m. Compare this with your weight. Assume mass of each person is 60 kg and use point charge approximation.

Given

$$n = 10^{28}, r = 1\text{m}, m = 60\text{kg}, n' = 1\% \quad 10^{28} = \frac{1}{100} \times 10^{28} = 10^{26} \quad F_e = ? , \quad w = ?$$

Solution

$$(i) F_e = \frac{1}{4\pi\epsilon_0} \frac{q q'}{r^2}$$

$$q = ne = 10^{26} \times 1.6 \times 10^{-19} \\ = 1.6 \times 10^7 \text{C}$$

$$q' = n'e = 10^{26} \times 1.6 \times 10^{-19} \\ = 1.6 \times 10^7 \text{C}$$

$$F_e = \frac{9 \times 10^9 \times 1.6 \times 10^7 \times 1.6 \times 10^7}{1^2}$$

$$F_e = 9 \times 2.56 \times 10^{23}$$

$$F_e = 23.04 \times 10^{23} \text{N}$$

$$\therefore F_e = 23 \times 10^{23} \text{N}$$

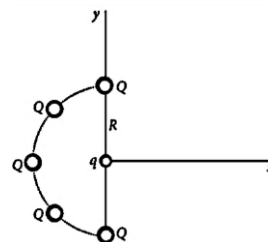
$$(ii) \text{Weight, } w = mg = 60 \times 9.8$$

$$w = 588 \text{N}$$

$$\frac{F_e}{w} = \frac{23 \times 10^{21}}{588}$$

$$\therefore \frac{F_e}{w} = 3.9 \times 10^{21}$$

3. Five identical charges Q are placed equidistant on a semicircle as shown in the figure. Another point charge q is kept at the center of the circle of radius R. Calculate the electrostatic force experienced by the charge q.



To find: Force experienced by q = ?

Solution

$$Q_1 = Q_2 = Q_3 = Q_4 = Q_5 = Q$$

- Forces acting on q due to Q_1 and Q_5 are equal and opposite.

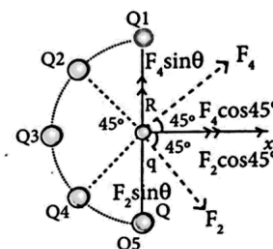
- Hence $\vec{F}_1$ & $\vec{F}_5$ get cancelled.

- Net force is zero

- Forces acting on q due to Q_2 ($\vec{F}_2$) and Q_4 (i.e. $\vec{F}_4$) is resolved into two two components.

- $F_2 \sin \theta$ and $F_4 \sin \theta$ are equal in magnitude but opposite in direction, get cancelled.

- $F_2 \cos \theta$ and $F_4 \cos \theta$ are horizontal components acts in same direction, gets added.



Force acting on q due to Q_3 is $\vec{F}_3$.

Total force acting on q is

$$\vec{F} = \vec{F}_3 \hat{i} + F_2 \cos \theta \hat{i} + F_4 \cos \theta \hat{i}$$

($\theta = 45^\circ$)

$$\vec{F} = \frac{kqQ}{R^2} \hat{i} + \frac{kqQ}{R^2} \cos 45^\circ \hat{i} + \frac{kqQ}{R^2} \cos 45^\circ \hat{i}$$

$$= \frac{kqQ}{R^2} \hat{i} \left[1 + \frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}} \right]$$

$$= \frac{kqQ}{R^2} \hat{i} \left[1 + \frac{2}{\sqrt{2}} \right]$$

$$= \frac{kqQ}{R^2} \hat{i} \left[1 + \frac{\sqrt{2}\sqrt{2}}{\sqrt{2}} \right]$$

$$\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{qQ}{R^2} [1 + \sqrt{2}] \hat{i} \text{ N} \quad \left(k = \frac{1}{4\pi\epsilon_0} \right)$$

4. Suppose a charge +q on Earth's surface and another +q charge is placed on the surface of the Moon. (a) Calculate the value of q required to balance the gravitational attraction between Earth and Moon (b) Suppose the distance between the Moon and Earth is halved, would the charge q change?

Given: $M_E = 5.9 \times 10^{24} \text{ kg}$, $M_M = 7.9 \times 10^{22} \text{ kg}$, To find: (i) $q = ?$ (ii) If $r = \frac{r}{2}$, $q = ?$

Solution

(i) $F_e = F_g$

$$\frac{1}{4\pi\epsilon_0} \frac{q \cdot q}{r^2} = \frac{GM_E M_M}{r^2}$$

$$9 \times 10^9 \times q^2 = 6.67 \times 10^{-11} \times 5.9 \times 10^{24} \times 7.9 \times 10^{22}$$

$$q^2 = \frac{6.67 \times 5.9 \times 7.9 \times 10^{35}}{9 \times 10^9}$$

$$q = \sqrt{\frac{6.67 \times 5.9 \times 7.9 \times 10^{26}}{9}}$$

$$q = 10^{13} \sqrt{\frac{6.67 \times 5.9 \times 7.9}{9}}$$

$$\therefore q = 5.87 \times 10^{13} \text{ C.}$$

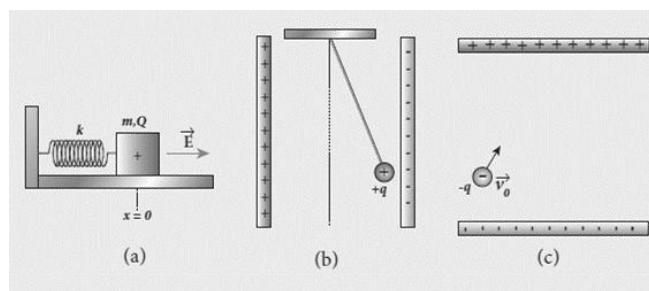
(ii) $kq^2 = GM_E M_M$

If $r = \frac{r}{2}$. The charge 'q' will not change

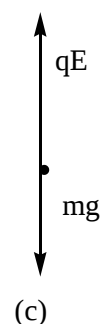
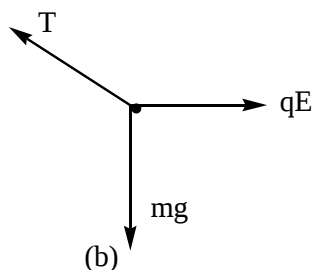
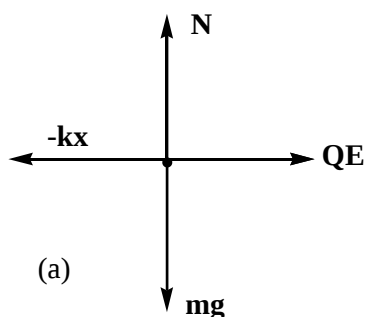
There is no r term

5. Draw the free body diagram for the following charges as shown in the figure

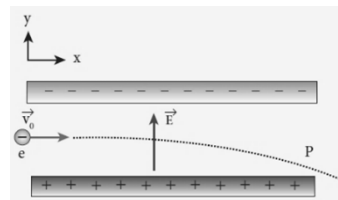
(a), (b) and (c).



Solution



6. Consider an electron travelling with a speed v_0 and entering into a uniform electric field $\vec{E}$ which is perpendicular to $\vec{v}_0$ as shown in the Figure. Ignoring gravity, obtain the electron's acceleration, velocity and position as functions of time.



Solution

(i) $F = ma, a = \frac{F}{m}$

$\therefore$ force experienced by e^- (F) = eE

$\therefore$ acceleration, $\vec{a} = \frac{eE}{m}(-\hat{j}) = -\frac{eE}{m}\hat{j}$

(ii) velocity ($\vec{v}$):

$$\vec{v} = \vec{u} + \vec{a}t, \vec{u} = v_0\hat{i}, \vec{a} = -\frac{eE}{m}\hat{j}$$

$$\vec{v} = v_0\hat{i} - \frac{eE}{m}t\hat{j}$$

(iii) Position vector ($\vec{r}$):

$$\vec{s} = \vec{u}t + \frac{1}{2}\vec{a}t^2$$

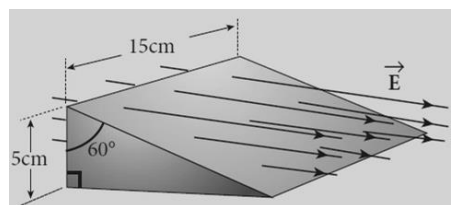
$$\vec{r} = v_0t\hat{i} + \frac{1}{2}\left(-\frac{eE}{m}\hat{j}\right)t^2$$

$$\vec{r} = v_0t\hat{i} - \frac{1}{2}\frac{eE}{m}t^2\hat{j}$$

7. A closed triangular box is kept in an electric field of magnitude

$$E = 2 \times 10^3 \text{ NC}^{-1} \text{ as shown in the figure.}$$

Calculate the electric flux through the (a) vertical rectangular surface (b) slanted surface and (c) entire surface.



field

Given: $E = 2 \times 10^3 \text{ NC}^{-1}$, $\phi_E = ?$

Solution

a) Vertical rectangle surface

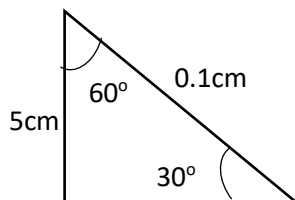
$$\phi_E = EA \cos \theta, A = 15 \text{ cm} \times 5 \text{ cm}$$

$$A = 75 \times 10^{-4} \text{ m}^2$$

$$\phi_E = 2 \times 10^3 \times 75 \times 10^{-4} \times \cos 180^\circ$$

$$= 150 \times 10^{-1}$$

$$\phi_E = 15 \text{ N m}^2 \text{ C}^{-1}$$



b) Slanted surface :

$$\phi_E = EA \cos \theta$$

Area of the slanted surface,

$$A = 15 \times 10^2 \times 10 \times 10^{-2} \text{ m}^2$$

$$A = 150 \times 10^{-4} \text{ m}^2$$

$$\phi_E = 2 \times 10^3 \times 150 \times 10^{-4} \times \cos 60^\circ$$

$$\phi_E = 300 \times 10^{-1} \times \frac{1}{2}$$

$$\phi_E = 15 \text{ N m}^2 \text{ C}^{-1}$$

Horizontal surface

$$\theta = 90^\circ, \cos 90^\circ = 0$$

$$\phi_E = 0$$

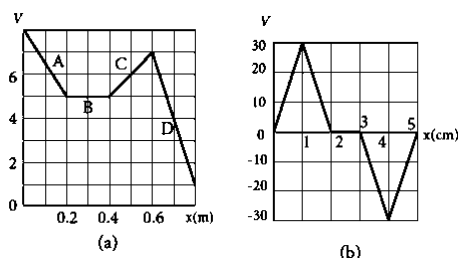
c) Entire surface:

$$\phi_{\text{Total}} = \phi_{\text{V.S}} + \phi_{\text{S.S}} + \phi_{\text{H.S}}$$

$$= 15 - 15 + 0 = \therefore$$

Net flux is zero

8. The electrostatic potential is given as a function of x in figure (a) and (b). Calculate the corresponding electric fields in regions A, B, C and D. Plot the electric field as a function of x for the figure (b).



Solution

For figure (a)

(i) Region A:

$$E_x = -\frac{dV}{dx}$$

From 0 to 0.2 m, slope is -ve (negative)

$$\therefore E_x = -\left(-\frac{dV}{dx}\right) = \frac{dV}{dx} = \frac{3}{0.2} = 15 \text{ Vm}^{-1}$$

(iii) Region C:

From 0.4 m to 0.6 m, slope is +ve

$$E_x = -\frac{dV}{dx} = -\frac{2}{0.2} = -10 \text{ Vm}^{-1}$$

(iv) Region D:

From 0.6 m to 0.8 m, slope is -ve

$$E_x = -\left(-\frac{dV}{dx}\right) = \frac{dV}{dx} = \frac{6}{0.2} = 30 \text{ Vm}^{-1}$$

For figure (b):

(i) From 0 to 1 m, slope is +ve (positive)

$$E_x = -\frac{dV}{dx} = -\frac{30}{1}$$

$$E_x = -30 \text{ Vcm}^{-1}$$

Electric field as a function of 'x' diagram for 'b' is

(ii) Region B:

From 0.2m to 0.4m, potential is constant.

$$V = 5\text{V},$$

$$E_x = -\frac{dV}{dx} = 0 \quad (V = \text{constant})$$

(ii) From 1 to 2 cm, slope is -ve

$$E_x = -\left(-\frac{dV}{dx}\right) = \frac{dV}{dx} = \frac{30}{1} = 30 \text{ Vcm}^{-1}$$

(iii) From 2 to 3 cm, $V = 0$

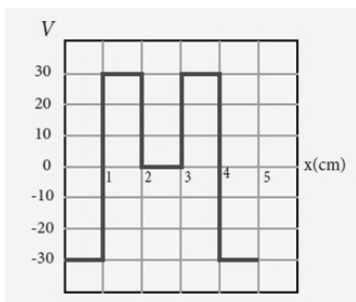
$$E_x = -\frac{dV}{dx} = 0$$

(iv) From 3 to 4cm, slope is -ve (negative)

$$E_x = -\left(-\frac{dV}{dx}\right) = \frac{dV}{dx} = \frac{30}{1} = 30 \text{ Vcm}^{-1}$$

(v) From 4 to 5 cm, slope is +ve (positive)

$$E_x = -\frac{dV}{dx} = -\frac{30}{1} = -30 \text{ Vcm}^{-1}$$



(b)

9. A spark plug in a bike or a car is used to ignite the air-fuel mixture in the engine. It consists of two electrodes separated by a gap of around 0.6 mm gap as shown in the figure.



To create the spark, an electric field of magnitude $3 \times 10^6 \text{ Vm}^{-1}$ is required.

- What potential difference must be applied to produce the spark?
- If the gap is increased, does the potential difference increase, decrease or remains the same?
- find the potential difference if the gap is 1 mm.

Given:

$$E = 3 \times 10^6 \text{ Vm}^{-1}, d = 0.6 \text{ mm} = 6 \times 10^{-4} \text{ m}$$

Solution:

a) Potential difference

$$V = E \times d$$

$$V = 3 \times 10^6 \times 6 \times 10^{-4}$$

$$= 18 \times 10^2 \text{ V}$$

$$V = 1800 \text{ V}$$

b) $V \propto d$

c) If $d = 1 \text{ mm}$,

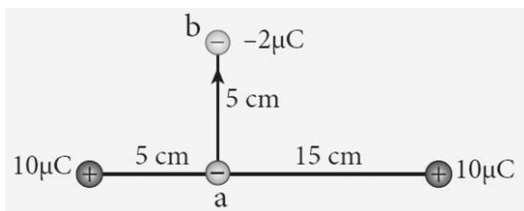
$$V = E \times d$$

$$V = 3 \times 10^6 \times 1 \times 10^{-3}$$

$$V = 3 \times 10^3 \text{ V}$$

$$V = 3000 \text{ V}$$

10. A point charge of $+10 \mu\text{C}$ is placed at a distance of 20 cm from another identical point charge of $+10 \mu\text{C}$. A point charge of $-2 \mu\text{C}$ is moved from point a to b as shown in the figure. Calculate the change in potential energy of the system? Interpret your result.



Given:

$$q_1 = 10\mu\text{C}, q_2 = -2\mu\text{C}, r_1 = 5\text{ cm}, r_2 = 15\text{ cm}$$

Solution

$$r'_1 = \sqrt{5^2 + 5^2} = \sqrt{50} = 5\sqrt{2}\text{ cm}$$

$$r'_2 = \sqrt{15^2 + 5^2} = \sqrt{250} = \sqrt{25 \times 10} = 5\sqrt{10}\text{ cm}$$

change in P. E $\Delta U = ?$

(i) Initial potential energy (U_i) when $-2\mu\text{C}$ charge at 'a'

$$\begin{aligned} U_i &= \frac{1}{4\pi\epsilon_0} \frac{q_1 q}{r_1} + \frac{1}{4\pi\epsilon_0} \frac{q_2 q}{r_2} \\ &= \frac{q_1 q}{4\pi\epsilon_0} \left[\frac{1}{r_1} + \frac{1}{r_2} \right] \quad [q_1 = q_2] \\ &= 9 \times 10^9 \times (-2 \times 10^{-6}) \times 10 \times 10^{-6} \times \left[\frac{1}{5} + \frac{1}{15} \right] \times \frac{1}{10^{-2}} \\ &= -18 \times 10^{-2} \times \frac{4}{15} \times \frac{1}{10^{-2}} \\ &= -\frac{24}{5} \end{aligned}$$

$$U_i = -4.85\text{ J}$$

(ii) Final potential energy (U_f), when a point charge ($-2\mu\text{C}$) moved to 'b'

$$\begin{aligned} U_f &= \frac{1}{4\pi\epsilon_0} \frac{q_1 q}{r'_1} + \frac{1}{4\pi\epsilon_0} \frac{q_2 q}{r'_2} \\ &= \frac{q_1 q}{4\pi\epsilon_0} \left[\frac{1}{r'_1} + \frac{1}{r'_2} \right] \quad (q_1 = q_2) \\ &= 9 \times 10^9 \times (-2 \times 10^{-6}) \times 10 \times 10^{-8} \times \left[\frac{1}{5\sqrt{2}} + \frac{1}{5\sqrt{10}} \right] \\ &= \frac{-18 \times 10^{-2}}{5 \times 10^{-2}} \times \left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{10}} \right] \\ &= -3.6 \times \left[\frac{\sqrt{2}}{\sqrt{2} \times \sqrt{2}} + \frac{\sqrt{10}}{\sqrt{10} \times \sqrt{10}} \right] \\ &= -3.6 \times \left[\frac{1.414}{2} + \frac{3.16}{10} \right] \\ &= -3.6 \times [0.707 + 0.316] \\ &= -3.6 \times 1.023 \end{aligned}$$

$$U_f = -3.683\text{ J}$$

$\therefore$ Change in potential energy

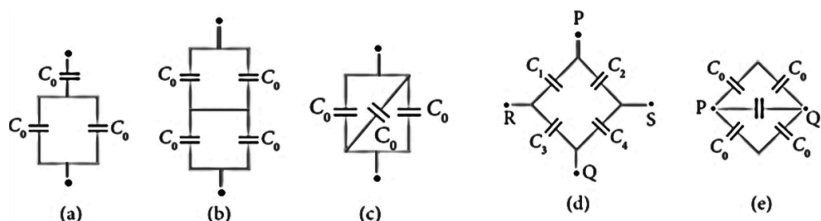
$$\Delta U = U_f - U_i$$

$$= -3.683 - (-4.8)$$

$$= 1.117 \text{ J}$$

$$\Delta U = 1.12 \text{ J}$$

11. Calculate the resultant capacitances for each of the following combinations of capacitors.



Solution:

(i) The equivalent capacitance of capacitors connected in series: $\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \dots$

The equivalent capacitance in capacitors connected in parallel: $C_p = C_1 + C_2 + C_3 + \dots$

Figure (a):

c_0 and c_0 in parallel,

$$C_p = c_0 + c_0 = 2c_0$$

c_0 & $2c_0$ in series,

$$\frac{1}{C_s} = \frac{1}{c_0} + \frac{1}{2c_0} = \frac{2+1}{2c_0} = \frac{3}{2c_0}$$

$$\therefore C_s = \frac{2c_0}{3}$$

Figure (b):

c_0 and c_0 in parallel,

$$C_p = c_0 + c_0 = 2c_0$$

$2c_0$ and $2c_0$ are in series,

$$\frac{1}{C_s} = \frac{1}{2c_0} + \frac{1}{2c_0} = \frac{2}{2c_0} = \frac{1}{c_0}$$

$$\therefore C_s = c_0$$

Figure (c):

Now, c_0 , c_0 and c_0 in parallel,

$$C_p = c_0 + c_0 + c_0$$

$$\therefore C_p = 3c_0$$

Figure (d):

Equivalent capacitance between P & Q

Now c_1 and c_3 in series

$$\frac{1}{C_{s1}} = \frac{1}{c_1} + \frac{1}{c_3} = \frac{c_3+c_1}{c_1c_3}; C_{s1} = \frac{c_1c_3}{c_1+c_3}$$

c_2 and c_4 in series

$$\frac{1}{C_{s2}} = \frac{1}{c_2} + \frac{1}{c_4} = \frac{c_4+c_2}{c_2c_4}; C_{s2} = \frac{c_2c_4}{c_2+c_4}$$

Now, C_{s1} and C_{s2} in parallel,

$$C_{PQ} = C_{s1} + C_{s2}$$

$$= \frac{c_1c_3}{c_1+c_3} + \frac{c_2c_4}{c_2+c_4}$$

$$C_{PQ} = \frac{c_1c_3(c_2+c_4) + c_2c_4(c_1+c_3)}{(c_1+c_3)(c_2+c_4)}$$

Equivalent capacitance between R & S:

Now c_1 and c_2 in series

$$\frac{1}{C_{s_1}} = \frac{1}{c_1} + \frac{1}{c_2} = \frac{c_2 + c_1}{c_1 c_2}; \quad C_{s_1} = \frac{c_1 c_2}{c_1 + c_2}$$

c_3 and c_4 in series

$$\frac{1}{C_{s_2}} = \frac{1}{c_3} + \frac{1}{c_4} = \frac{c_4 + c_3}{c_3 c_4}; \quad C_{s_2} = \frac{c_3 c_4}{c_3 + c_4}$$

Now, C_{s_1} and C_{s_2} in parallel,

$$C_{RS} = C_{s_1} + C_{s_2}$$

$$= \frac{c_1 c_2}{c_1 + c_2} + \frac{c_3 c_4}{c_3 + c_4}$$

$$C_{RS} = \frac{c_1 c_2 (c_3 + c_4) + c_3 c_4 (c_1 + c_2)}{(c_1 + c_2)(c_3 + c_4)}$$

$$C_{RS} = \frac{c_1 c_2 c_3 + c_1 c_2 c_4 + c_1 c_3 c_4 + c_2 c_3 c_4}{(c_1 + c_2)(c_3 + c_4)}$$

$$C_{PQ} = \frac{c_1 c_2 c_3 + c_1 c_3 c_4 + c_1 c_2 c_4 + c_2 c_3 c_4}{(c_1 + c_3)(c_2 + c_4)}$$

Figure (e):

Now, c_0 and c_0 in series,

$$\frac{1}{C_{s_1}} = \frac{1}{c_0} + \frac{1}{c_0} = \frac{2}{c_0}; \quad C_{s_1} = \frac{c_0}{2}$$

$$\frac{1}{C_{s_2}} = \frac{1}{c_0} + \frac{1}{c_0} = \frac{2}{c_0}; \quad C_{s_2} = \frac{c_0}{2}$$

Now, C_{s_1} , c_0 and C_{s_2} in parallel

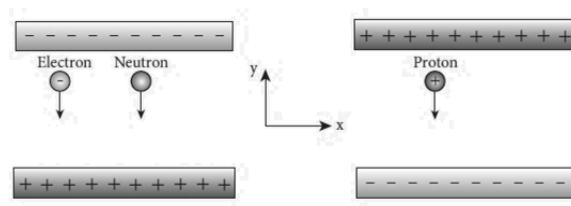
$$C_p = C_{s_1} + c_0 + C_{s_2}$$

$$= \frac{c_0}{2} + c_0 + \frac{c_0}{2}$$

$$C_p = \frac{c_0 + 2c_0 + c_0}{2} = \frac{4c_0}{2}$$

$$C_p = 2c_0$$

12. An electron and a proton are allowed to fall through the separation between the plates of a parallel plate capacitor of voltage 5 V and separation distance $h = 1$ mm as shown in the figure.



(a) Calculate the time of flight for both electron and proton

(b) Suppose if a neutron is allowed to fall, what is the time of flight?

(c) Among the three, which one will reach the bottom first?

Given:

$$m_p = 1.6 \times 10^{-27} \text{ kg}, \quad m_e = 9.1 \times 10^{-31} \text{ kg}, \quad g = 10 \text{ ms}^{-2}$$

Solution:

$$h = 1 \text{ mm} = 1 \times 10^{-3} \text{ m}; \quad V = 5 \text{ volt} \quad E = \frac{V}{h} = 5 \times 10^3 \text{ NC}^{-1}$$

(i) Time of flight (t_f) for electron,

$$s = ut + \frac{1}{2}at^2.$$

$$s = h, u = 0, a = \frac{F}{m} = \frac{eE}{m}, t = t_e$$

$$h = 0 + \frac{1}{2} \left(\frac{eE}{m_e} \right) t_e^2 = \frac{1}{2} \left(\frac{eE}{m_e} \right) t_e^2$$

$$t_e = \sqrt{\frac{2m_e h}{eE}} = \sqrt{\frac{2 \times 9.1 \times 10^{-31} \times 1 \times 10^{-3}}{1.6 \times 10^{-19} \times 5 \times 10^3}}$$

$$t_e = \sqrt{\frac{18.2 \times 10^{-18}}{8}} = \frac{10^{-9}}{2} \sqrt{9.1}$$

$$t_e = \frac{3 \times 10^{-9}}{2}$$

$$t_e = 1.5 \text{ ns}$$

(ii) Time of flight for proton (t_p):

$$s = ut + \frac{1}{2}at^2;$$

$$s = h, u = 0, t = t_p, a = \frac{Ee}{m_p}$$

$$h = 0 + \frac{1}{2} \left(\frac{eE}{m_p} \right) t_p^2$$

$$t_p = \sqrt{\frac{2m_p h}{eE}} = \sqrt{\frac{2 \times 1.6 \times 10^{-27} \times 1 \times 10^{-3}}{1.6 \times 10^{-19} \times 5 \times 10^3}}$$

$$t_p = \sqrt{0.4 \times 10^{-14}} = 10^{-7} \sqrt{0.4}$$

$$t_p = 6.3 \times 10^{-7} \times 10^{-1} = 6.3 \times 10^{-8} \text{ s}$$

$$t_p = \mathbf{63 \text{ ns}}$$

(iii) Time of flight for neutron (t_n):

$$s = ut + \frac{1}{2}at^2;$$

$$s = h, u = 0, t = t_n, a = g$$

$$t_n = \sqrt{\frac{2h}{g}} = \sqrt{\frac{2 \times 1 \times 10^{-3}}{10}}$$

$$t_n = 10^{-2} \sqrt{2} = 1.414 \times 10^{-2} \text{ s}$$

$$= 14.14 \times 10^{-3} \text{ s}$$

$$t_n = 14.14 \text{ ms}$$

$$\therefore t_e < t_p < t_n$$

Therefore, electrons will reach the bottom first.

13. During a thunder storm, the movement of water molecules within the clouds creates friction, partially causing the bottom part of the clouds to become negatively charged. This implies that the bottom of the cloud and the ground act as a parallel plate capacitor. If the electric field between the cloud and ground exceeds the dielectric breakdown of the air ($3 \times 10^6 \text{ Vm}^{-1}$), lightning will occur.

(a) If the bottom part of the cloud is 1000 m above the ground, determine the electric potential difference that exists between the cloud and ground.

(b) In a typical lightning phenomenon, around 25C of electrons are transferred from cloud to ground. How much electrostatic potential energy is transferred to the ground?

Given: $E = 3 \times 10^6 \text{ Vm}^{-1}$; $d = 1000 \text{ m}$, $q = 25 \text{ C}$, $V = ?$, $U = ?$

Solution

(i) Electric potential difference

$$V = E \times d$$

$$V = 3 \times 10^6 \times 1000 = 3 \times 10^9 \text{ V}$$

(ii) Electrostatic potential energy (U)

$$U = V \times q = 3 \times 10^9 \times 25 = 75 \times 10^9 \text{ J}$$

14. For the given capacitor configuration

(a) Find the charges on each capacitor

(b) potential difference across them

(c) energy stored in each capacitor

Solution

$$V = 9 \text{ V}, C_a = 8 \mu\text{F}, C_b = 6 \mu\text{F}, C_c = 2 \mu\text{F}, C_d = 8 \mu\text{F}$$

$$C_b \text{ and } C_c \text{ in parallel: } C_{bc} = C_b + C_c = 6 + 2 = 8 \mu\text{F}$$

Potential difference in each capacitor:

$$V_a = \frac{V}{3} = \frac{9}{3} = 3 \text{ V} \quad V_c = \frac{V}{3} = \frac{9}{3} = 3 \text{ V}$$

$$V_b = \frac{V}{3} = \frac{9}{3} = 3 \text{ V} \quad V_d = \frac{V}{3} = \frac{9}{3} = 3 \text{ V}$$

Charge on each capacitor

$$q_a = C_a V_a = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} \text{ C} = 24 \mu\text{C}$$

$$q_b = C_b V_b = 6 \times 10^{-6} \times 3 = 18 \times 10^{-6} \text{ C} = 18 \mu\text{C}$$

$$q_c = C_c V_c = 2 \times 10^{-6} \times 3 = 6 \times 10^{-6} \text{ C} = 6 \mu\text{C}$$

$$q_d = C_d V_d = 8 \times 10^{-6} \times 3 = 24 \times 10^{-6} \text{ C} = 24 \mu\text{C}$$

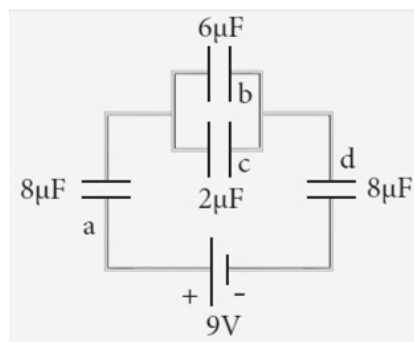
Energy stored in each capacitor

$$U_a = \frac{1}{2} C_a V_a^2 = \frac{1}{2} \times 8 \times 10^{-6} \times (3)^2 = 36 \times 10^{-6} \text{ J}. \therefore U_a = 36 \mu\text{J}$$

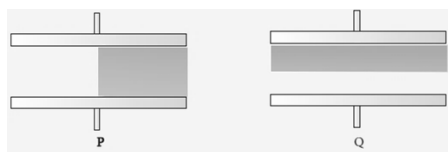
$$U_b = \frac{1}{2} C_b V_b^2 = \frac{1}{2} \times 6 \times 10^{-6} \times (3)^2 = 27 \times 10^{-6} \text{ J} = 27 \mu\text{J}$$

$$U_c = \frac{1}{2} C_c V_c^2 = \frac{1}{2} \times 2 \times 10^{-6} \times (3)^2 = 9 \times 10^{-6} \text{ J} = 9 \mu\text{J}$$

$$U_d = \frac{1}{2} C_d V_d^2 = \frac{1}{2} \times 8 \times 10^{-6} \times (3)^2 = 36 \times 10^{-6} \text{ J} = 36 \mu\text{J}$$



15. Capacitors P and Q have identical cross sectional areas A and separation d. The space between the capacitors is filled with a dielectric of dielectric constant ϵ_r as shown in the figure. Calculate the capacitance of capacitors P and Q.



Capacitor 'P'

capacitance of a parallel plate capacitor, $C = \frac{\epsilon_0 A}{d}$, with dielectric, $C = \frac{\epsilon_r \epsilon_0 A}{d}$

In capacitor 'P': C_1 and C_2 parallel $\rightarrow C_p = C_1 + C_2$

$$C_1 = \frac{\epsilon_0 A}{d}; \text{ here } A = \frac{A}{2}$$

$$C_1 = \frac{\epsilon_0 \left(\frac{A}{2}\right)}{d} = \frac{\epsilon_0 A}{2d}$$

$$C_2 = \frac{\epsilon_r \epsilon_0 \left(\frac{A}{2}\right)}{d} = \frac{\epsilon_r \epsilon_0 A}{2d}$$

$$C_p = \frac{\epsilon_0 A}{2d} + \frac{\epsilon_r \epsilon_0 A}{2d}$$

$$C_p = \frac{\epsilon_0 A}{2d} (1 + \epsilon_r)$$

In capacitor ‘Q’:

$$\text{Now, } A = A, d = \frac{d}{2}$$

$$C_1 \text{ and } C_2 \text{ are in series} \rightarrow \frac{1}{C_Q} = \frac{1}{C_1} + \frac{1}{C_2};$$

$$C_1 = \frac{\epsilon_r \epsilon_0 A}{\frac{d}{2}}; \quad C_1 = \frac{2\epsilon_r \epsilon_0 A}{d},$$

$$C_2 = \frac{\epsilon_0 A}{\frac{d}{2}}; \quad C_2 = \frac{2\epsilon_0 A}{d}$$

$$\frac{1}{C_Q} = \frac{d}{2\epsilon_r \epsilon_0 A} + \frac{d}{2\epsilon_0 A}$$

$$= \frac{d}{2\epsilon_0 A} \left[\frac{1}{\epsilon_r} + 1 \right]$$

$$\frac{1}{C_Q} = \frac{d}{2\epsilon_0 A} \left[\frac{1 + \epsilon_r}{\epsilon_r} \right]$$

$$C_Q = \frac{2\epsilon_0 A}{d} \left[\frac{\epsilon_r}{1 + \epsilon_r} \right]$$

UNIT - 2 CURRENT ELECTRICITY

Important Questions

Two Marks	
Book Back	Book inside
1. Why current is a scalar? 2. Distinguish between drift velocity and mobility 3. State microscopic model of ohm's law 4. State macroscopic form of Ohm's law or State Ohm's law 5. Define temperature coefficient of resistance 6. Define Joule's law of heating. 7. What is Seebeck effect? 8. What is Thomson effect? 9. What is Peltier effect? 10. State the Applications of Seebeck effect	1. Why circuit breaker is advantageous over fuse? 2. Why repairing the electrical connection with the wet skin is always dangerous? 3. What is carbon resistor? 4. Define transition or critical temperature 5. Define Joule's heating effect.
Three Marks	
1. Obtain the macroscopic form of Ohm's law from its microscopic form and discuss its limitation 2. Explain the equivalent resistance of a series and parallel resistor network 3. Explain the determination of the internal resistance of a cell using voltmeter 4. State and explain Kirchhoff's rules 5. How the emf of two cells are compared using potentiometer?	1. Explain the determination of internal resistance of a cell by potentiometer
Five marks	
1. Describe the microscopic model of current and obtain general form of Ohm's law 2. Obtain the condition for bridge balance in Wheatstone's bridge. 3. Explain the determination of unknown resistance using meter bridge	

Important Formulae

1. Instantaneous current $I = \frac{dq}{dt} = \frac{ne}{t}$;
2. Current through conductor $I = nAev_d$
3. Acceleration of electron $a = \frac{eE}{m}$;
4. Drift velocity $v_d = \frac{eE}{m}\tau$
5. Mobility $\mu = \frac{e\tau}{m}$;
6. Current density $J = nev_d = \frac{I}{A} = \sigma E$
7. Potential difference $V = IR$;
8. Resistance of the wire $R = \frac{\rho l}{A}$
9. Specific resistance $\rho = \frac{RA}{l}$;
10. Electric power, $P = VI = I^2R = \frac{V^2}{R}$
11. Conditions to balance Wheatstone's network $\frac{P}{Q} = \frac{R}{S}$
12. Conductivity $\sigma = \frac{1}{\rho} = \frac{1}{RA} \Omega^{-1}m^{-1}$
13. Ratio between resistance of the same material wires $\frac{R_2}{R_1} = \frac{(l_2 r_1^2)}{(l_1 r_2^2)}$
14. Heat produced $H = I^2RT$
15. In Metre bridge: $P = Q \frac{l_1}{l_2}$
16. Specific resistance $\rho = \frac{P\pi r^2}{L}$;
17. Equivalent resistance
In series: $R_s = R_1 + R_2 + R_3$
In parallel: $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

18. Resistance of a conductor at temperature $t^\circ C$, $R_T = R_0[1 + \alpha(T - T_0)]$
19. Temperature coefficient of resistance
 $\alpha = \frac{R_T - R_0}{R_0 \Delta T} = \frac{\Delta R}{R_0 \Delta T}$
21. Internal resistance r of the cell
 (i) emf & potential difference given
 $r = \left(\frac{\varepsilon - V}{V} \right) R$
 (ii) balancing length $[l_2, l_1]$ given
 $r = R \left(\frac{l_1 - l_2}{l_2} \right)$
22. Potentiometer: $\varepsilon \propto l \Rightarrow \varepsilon = Irl$
23. Unknown emf $\varepsilon_2 = \varepsilon \frac{l_2}{l_1}$
24. Cells in series connection $I = \frac{n\varepsilon}{nr + R}$
25. Cells in parallel connection $I = \frac{n\varepsilon}{r + nR}$
26. Colour codes & resistance value

Colour	Number	Colour	Number
Black	0	Brown	1
Red	2	Orange	3
Yellow	4	Green	5
Blue	6	Violet	7
Grey	8	White	9

27. Tolerance

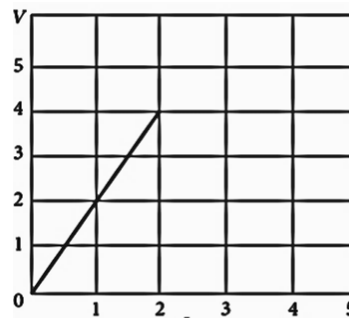
Silver: $\pm 10\%$ Gold: $\pm 5\%$ Colourless: 20%

Textbook One Mark Solved

1. The following graph shows current versus voltage values of some unknown conductor. What is the resistance of this conductor?

- a) 2 ohm
b) 4 ohm
c) 8 ohm
d) 1 ohm

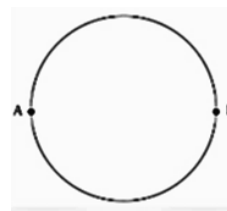
Hint: $R = \frac{dV}{dI} = \frac{4-0}{2-0} = 2$



Answer: (a) 2 ohm

2. A wire of resistance 2 ohms per meter is bent to form a circle of radius 1m. The equivalent resistance between its two diametrically opposite points, A and B as shown in the figure is

- a) $\pi \Omega$
c) $2\pi\Omega$
- b) $\pi / 2 \Omega$
d) $\pi / 4 \Omega$



Hint: Circumference (L) = $2\pi R = 2\pi \times 1 = 2\pi$. Resistance R = $2\pi \times 2 = 4\pi$

Equivalent resistance when connected in parallel $R_p = \frac{R}{n} = \frac{2\pi}{2} = \pi$

Answer: (a) $\pi \Omega$

3. A toaster operating at 240 V has a resistance of 120 Ω . The power is

- a) 400 W b) 2 W c) 480 W d) 240 W

$$\text{Hint: } P = \frac{V^2}{R} = \frac{240 \times 240}{120} = 480V$$

Answer: c) 480 W

4. A carbon resistor of $(47 \pm 4.7) \text{ k } \Omega$ to be marked with rings of different colours for its identification. The colour code sequence will be

- a) Yellow – Green – Violet – Gold b) Yellow – Violet – Orange – Silver
c) Violet – Yellow – Orange – Silver d) Green – Orange – Violet – Gold

Hint: Yellow – 4, Violet – 7, Orange - 10^3 – k Ω , Silver tolerance – 10 %

Answer: b) Yellow – Violet – Orange – Silver

5. What is the value of resistance of the following resistor?



- (a) 100 k Ω (b) 10 k Ω (c) 1k Ω (d) 1000 k Ω

Hint: Brown- 1, Black – 0, Yellow - 10^4 . Resistance value = 10×10^4

Answer: (a) 100 k Ω

6. Two wires of A and B with circular cross section made up of the same material with equal lengths. Suppose $R_A = 3 R_B$, then what is the ratio of radius of wire A to that of B?

- (a) 3 (b) $\sqrt{3}$ (c) $1/\sqrt{3}$ (d) $1/3$

Hint: $R \propto \frac{l}{a}$ where l is common. $\frac{R_A}{R_B} = \frac{\pi r_2^2}{\pi r_1^2}$; $\frac{r_1}{r_2} = \sqrt{\frac{R_B}{R_A}}$ where $R_A = 3 R_B$

Answer: (c) $1/\sqrt{3}$

7. A wire connected to a power supply of 230 V has power dissipation P_1 . Suppose the wire is cut into two equal pieces and connected parallel to the same power supply. In this case power dissipation is P_2 The ratio $\frac{P_2}{P_1}$ is

- (a) 1 (b) 2 (c) 3 (d) 4

Hint: Resistance before cutting the wire R , Resistance after cutting the wire $\frac{R}{2}$

Wires are connected in parallel $\frac{1}{R_p} = \frac{R_1 R_2}{R_1 + R_2} = \frac{R}{4}$, $P = \frac{V^2}{R}$ Ratio $\frac{P_2}{P_1} = \frac{R}{R_p} = \frac{4R}{R} = 4$

Answer: (d) 4

8. In India electricity is supplied for domestic use at 220 V. It is supplied at 110 V in USA. If the resistance of a 60W bulb for use in India is R , the resistance of a 60W bulb for use in USA will be

- (a) R (b) $2R$ (c) $R/4$ (d) $R/2$

Hint: $P = \frac{V^2}{R}$

For India: $P_1 = \frac{V_1^2}{R_1}$, For USA $P_2 = \frac{V_2^2}{R_2}$, $P_1 = P_2$

Applying known values $\rightarrow R_2 = \frac{R}{4}$

Answer: (c) $\frac{R}{4}$

9. In a large building, there are 15 bulbs of 40W, 5 bulbs of 100W, 5 fans of 80W and 1 heater of 1kW are connected. The voltage of electric mains is 220V. The minimum capacity of the main fuse of the building will be

- (a) 14 A (b) 8 A (c) 10 A (d) 12 A

Hint: Total power consumed : $(15 \times 40) + (5 \times 100) + (5 \times 80) + 1 \times 1000 = 2500W$

Current $I = \frac{P}{V} = \frac{2500}{220} = 11.36 A$

Answer: (d) 12 A

c) copper increases & germanium decreases d) copper decreases & germanium increases

Hint: For conductors (copper) $\rho \propto T$. For semiconductors (germanium) $\rho \propto \frac{1}{T}$

Answer: d) copper decreases and germanium increases

15. In Joule's heating law, when R and t are constant, if the H is taken along the y axis and I^2 along the x axis, the graph is

a) straight line b) parabola c) circle d) ellipse

Hint: Since R and t are constant. $H \propto I^2$. On plotting we will get straight line

Answer: a) straight line

Additional One Marks Solved

1. If the resistance of a coil is 3 ohm at 20°C and $\alpha = 0.004/^\circ\text{C}$ then its resistance at 100°C is

a) 1.98 **b) 3.96 Ω** c) 7.92 d) 39.6 Ω

Solution:

$$\begin{aligned} R_{100} &= 3[1 + 0.004(100 - 20)] \\ &= 3[1 + 0.004 \times 80] \\ &= 3[1 + 0.32] = 3 \times 1.32 = 3.96 \Omega \end{aligned}$$

2. If the length of the conductor is doubled and its area is reduced to half of its value, then its resistance would be

a) Increased by two times **b) Increased by four times**
c) Decreased by four times d) Decreased by two times

3. The equivalent resistance of the following combination is $\frac{6}{5}$ ohm then the value of resistance

R_2 is

a) 3 Ω **b) 6 Ω** c) $\frac{5}{6} \Omega$ d) 1.5 Ω

Solution:

$$\frac{1}{R_1} + \frac{1}{R_2} = \frac{5}{6}$$

$$\frac{1}{2} + \frac{1}{x} = \frac{5}{6}. \text{ On solving } x = \mathbf{3 \Omega}$$

4. An electric bulb is marked as 100 W – 220 V. Then its resistance is

a) 282 Ω b) 968 Ω **c) 484 Ω** d) 0 Ω

Solution:

$$P = \frac{V^2}{R} \rightarrow R = \frac{V^2}{P} = \frac{(220)^2}{100} = 484 \Omega$$

5. Two wires have the same length. But, area of cross – section of one is 9 times that of the other. If the resistance of thinner wire be $300\ \Omega$, then resistance of the thicker wire is

- a) $66.6\ \Omega$ **b) $33.3\ \Omega$** c) $100\ \Omega$ d) $600\ \Omega$

Solution:

$$\frac{R_1}{R_2} = \frac{A_2}{A_1}, A_2 = 9 A_1, R_1 = 300\ \Omega, R_2 = ?$$

$$\frac{300}{R_2} = \frac{9A_1}{A_1} \rightarrow \frac{300}{R_2} = 9$$

$$R_2 = \frac{300}{9} = \frac{100}{3} = \mathbf{33.3\ \Omega}$$

6. If two wires are of same length one of them is twice as thick as the other. Then the resistance of two wires are in the ratio

- a) 1:2 **b) 1:4** c) 1:8 d) 1:16

Solution:

$$R = \rho \frac{l}{\pi r^2}, R \propto \frac{1}{r^2} \quad \therefore \frac{R_2}{R_1} = \left(\frac{r_1}{r_2}\right)^2$$

$$\text{If } r_2 = 2r_1 \text{ then } \frac{R_2}{R_1} = \left(\frac{r_1}{2r_1}\right)^2 = \left(\frac{1}{2}\right)^2 = \frac{1}{4}$$

$$R_1 : R_2 = 1 : 4$$

7. A uniform wire of length 2 m and cross-sectional area 10^{-7}m^2 carries a current of 1.6 A. If there are 10^{28} electrons in copper then its drift velocity is

- a) 2 mms^{-1} b) 5 mms^{-1} c) 1 ms^{-1} **d) 10 mms^{-1}**

Solution: $V_d = \frac{I}{neA} = \frac{1.6}{10^{28} \times 1.6 \times 10^{-19} \times 10^{-7}} = \mathbf{10\text{ mms}^{-1}}$

8. The internal resistance of a 2.1 V cell which gives a current of 0.2 A through a resistance of $10\ \Omega$ is

- a) $0.2\ \Omega$ **b) $0.5\ \Omega$** c) $0.8\ \Omega$ d) $1.0\ \Omega$

Solution:

$$I = \frac{E}{R+r} = 0.2 = \frac{2.1}{10+r}$$

$$0.2(10 + r) = 2.1$$

$$2 + 0.2r = 2.1$$

$$0.2r = 0.1 \rightarrow r = 0.5\ \Omega$$

9. The resistivity of a wire

- a) varies with its length b) varies with its mass
c) varies with its cross – section

d) does not depend on its length, cross – section and mass

10. Across a metallic conductor of non – uniform cross – sectional constant potential difference is applied. The quantity that remains constant along the conductor is

- a) electric field **b) current** c) drift velocity d) current density

11. If the power dissipated in the $9\ \Omega$ resistor in the following circuit is 36 W, then potential difference across the $2\ \Omega$ resistor is

- a) 2 V b) 4 V **c) 10 V** d) 8 V

12. Cell A having emf 2 V with internal resistance of $1\ \Omega$ is compared with another cell B having emf 2 V with internal resistance of $2\ \Omega$ using a potentiometer. The ratio of their respective balancing length is

- a) 1:2 b) 2:1 **c) 1:1** d) 3:4

Solution: Balancing lengths are same: $E_A = E_B$ $\therefore E_A : E_B = 1 : 1$

13. The graph between resistivity and temperature for nichrome alloy is

- a) straight line with negative slope **b) straight line with positive slope.**
c) Parabola d) hyperbola

14. In the case of insulators, as the temperature decreases, the resistivity

- a) decreases **b) increases**
c) remains constant d) becomes zero

15. Kirchhoff's two law for electrical circuits are the conservation of

- a) charge only b) both energy and momentum
c) energy only **d) both charge and energy**

16. A copper wire of length 2 m and area of cross – section $1.7 \times 10^{-6}\text{m}^2$ has a resistance of $2 \times 10^{-2}\ \Omega$. The resistivity of copper is

- a) $1.7 \times 10^{-8}\Omega\text{m}$** b) $1.9 \times 10^{-8}\Omega\text{m}$
c) $2.1 \times 10^{-7}\Omega\text{m}$ d) $2.3 \times 10^{-7}\Omega\text{m}$

Solution:

$$\rho = \frac{RA}{l} = \frac{2 \times 10^{-2} \times 1.7 \times 10^{-6}}{2} = 1.7 \times 10^{-8}\Omega\text{m}$$

17. A 10 m long wire of resistance $20\ \Omega$ is connected in series with a battery of emf 3V and a resistance of $10\ \Omega$. The potential gradient along the wire in volt per metre is

- a) 0.02 b) 0.1 **c) 0.2** d) 1.2

Solution:

$$\text{Potential difference across the wire} = \frac{20}{30} \times 3 = 2\text{V}$$

$$\text{Potential gradient} = \frac{V}{l} = \frac{2}{10} = 0.2\text{ V/m}$$

18. Resistance of the metal wire of length 10 cm is $2\ \Omega$. If the wire is stretched uniformly to 50 cm the resistance is

- a) $10\ \Omega$ **b) $50\ \Omega$** c) $5\ \Omega$ d) $25\ \Omega$

19. When current I flows through a wire, drift velocity of the electrons is v . The current I flows through another wire of the same material having double the length and area of cross – section, the drift velocity of the electrons will be

- a) $\frac{v}{4}$ b) $\frac{v}{2}$ **c) v** d) $2v$

Solution: $v_d = \frac{I}{nAe}$; $v'_d = \frac{2I}{(2A)ne} = v_d$

20. A cell of emf 2V and internal resistance $0.1\ \Omega$ is connected with a resistance of $3.9\ \Omega$. The voltage across the cell terminals will be

- a) 0.5 V b) 1.9 V **c) 1.95 V** d) 2 V

Solution:

$$V = \frac{ER}{R+r} = \frac{2 \times 3.9}{3.9+0.1} = 1.95\text{ V}$$

21. Five cells, each of emf E , are joined in parallel. The total emf of the combination is

- a) $5E$ b) $\frac{E}{5}$ **c) E** d) $\frac{5E}{2}$

22. A battery of emf 10 V and internal resistance $3\ \Omega$ is connected to a resistor. The current in the circuit is 0.5 A. The terminal voltage of the battery when the circuit is closed is

- a) 10 V b) Zero **c) 8.5 V** d) 1.5 V

Solution:

$$V = \varepsilon - Ir = 10 - (0.5 \times 3) = 8.5\text{ V}$$

23. A wire of resistance R is stretched to three times its original length. The new resistance is

- a) $3R$ **b) $9R$** c) $\frac{R}{3}$ d) $\frac{R}{9}$

$$R = \frac{\rho l}{A} \text{ which means } R \propto l$$

24. Which of the following has negative temperature coefficient of resistance?

- a) Copper b) Aluminium **c) Germanium** d) Iron

25. Ohm's law is applicable for

- (a) Complicated circuit **(b) simple circuit**
(c) Primary circuit (d) secondary circuit

26. Electric field of magnitude 570 N C^{-1} , is applied in the copper wire, the acceleration experienced by the electron is

- (a) $1.56 \times 10^{-2}\text{ m/s}^2$ (b) $1.56 \times 10^{-4}\text{ m/s}^2$

(c) $3.12 \times 10^{-2} \text{ m/s}^2$

(d) $1.001 \times 10^{14} \text{ m/s}^2$

Solution: $a = \frac{eE}{m}$

27. Potential difference V applied across a conductor is increased to $2V$, how will the drift velocity of the electron change

(a) increases by four times

(b) decreases by four times

(c) **increases by two times**

(d) remains same

Solution:

$$V_d = \frac{Ee\tau}{m} \quad V_d = \frac{Ve\tau}{lm} \quad V_d = \frac{2Ve\tau}{lm}$$

28. A Carbon resistor has three strips of red colour and a gold strip. The value of resistor

(a) $2250 \pm 5 \text{ ohm}$

(b) $2255 \pm 10 \text{ Ohm}$

(c) $2200 \pm 1 \text{ ohm}$

(d) **$2200 \pm 5 \text{ ohm}$**

29. If a wire is stretched to double of its length, new resistivity will be

(a) doubled

(b) tripled

(c) **remains same**

(d) none of these

Solution: No change in its resistivity because resistivity depends only on the nature of the material.

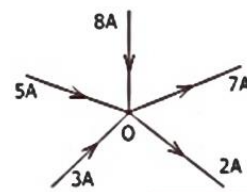
30. The value of current I at O in the adjoining circuit

(a) 7A

(b) 8A

(c) 9 A

(d) 10 A



Solution:

$$i = \text{current entering} - \text{current leaving} = 16 - 9 \quad i = 7A$$

31. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell

(a) 1.25 V

(b) **2.25 V**

(c) 5V

(d) 6V

Solution: $E_1/E_2 = l_1/l_2$

32. The resistance of the wire when its length is increased to twice its original length

(a) resistance becomes two times

(b) resistance becomes eight times

(c) **resistance becomes four times**

(d) resistance remain same

Solution: $R = \frac{\rho l}{A}$

33. A silver wire has a resistance of 2.1Ω at 27.5°C , and a resistance of 2.7Ω at 100°C . The temperature coefficient of resistivity of silver.

(a) **$0.0039 / ^\circ\text{C}$**

(b) $0.002 / ^\circ\text{C}$

(c) $0.006 / ^\circ\text{C}$

(d) $0.005 / ^\circ\text{C}$

Solution: $\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$; $R_1 = 2.1$, $R_2 = 2.7$, $T_1 = 27.5^\circ\text{C}$, $T_2 = 100^\circ\text{C}$

34. The temperature co-efficient of resistance for alloys is

- (a) low **(b) very low** (c) high (d) very high

35. The current flowing through a wire is $I = 6t^2 + 4t - 2$, here t is in second and I is in ampere. In this wire, what is the quantity of electric charge passing in time interval 1 sec to 2 sec?

- (a) 8C **(b) 18 C** (c) 20 C (d) 24 C

Solution: $Q = \int_1^2 Idt$

36. Peltier effect is the converse of

- a) Joule effect b) Raman effect
c) Thomson effect **d) Seebeck effect**

37. Area of cross section of a copper wire is equal to area of a square of 2mm length. It carries a current of 8A, the drift velocity of electrons (Density of free electrons in copper = $8 \times 10^{28} \text{ m}^{-3}$)

- (a) $1.56 \times 10^{-2} \text{ m/s}$ **(b) $1.56 \times 10^{-4} \text{ m/s}$** (c) $3.12 \times 10^{-2} \text{ m/s}$ (d) $3.12 \times 10^{-3} \text{ m/s}$

Solution: $v_d = \frac{I}{nAe} = \frac{8}{8 \times 10^{28} \times 2 \times 10^{-3} \times 1.6 \times 10^{-19}} = 1.56 \times 10^{-4}$

38. Which of the following has negative temperature coefficient of resistance

- (a) Fe **(b) C** (c) Mn (d) Ag

39. A parallel combination of three resistors takes a current of 7.5 A from 30 V supply. If two resistors are 10Ω and 12Ω find the resistance of unknown

- (a) 4Ω **(b) 15Ω** (c) 12Ω (d) 22Ω

Solution: $\frac{1}{R_{\text{net}}} = \frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

40. The masses of three wires of copper are in the ratio of 1: 3 : 5 and their length are in the ratio of 5:3:1. The ratio of their electrical resistance

- (a) 1:1:1 (b) 1 : 3 : 5 (c) 5 : 3 : 1 **(d) 125 : 15 : 1**

Solution: $R \propto \frac{l^2}{m}$

Short Answers - Book Back

1. Why current is a scalar?

Current I defined as the scalar product of the current density and area vector in which the charges cross.

$$I = \vec{J} \cdot \vec{A}$$

- ✓ Dot product of two vector quantity is a scalar form, so current is a scalar quantity.

2. Define Current Density

It is defined as the current per unit area of cross section of the conductor.

$$J = \frac{I}{A}$$

3. Distinguish between drift velocity and mobility

Drift velocity	Mobility
It is average velocity acquired by the electrons inside the conductor when it is subjected to an electric field	It is defined as the magnitude of the drift velocity per unit electric field
$v_d = a \tau$	$\mu = \frac{v_d}{E}$

4. State microscopic model of ohm's law

$$\vec{J} = \sigma \vec{E}$$

$\vec{J}$ Current density, σ – conductivity, $\vec{E}$ – Electric field.

It operates on a microscopic level relating the current density J to the conductivity σ and electric field E.

5. State macroscopic form of Ohm's law (OR) State Ohm's law

At constant temperature, steady current flowing through the conductor is directly proportional to potential difference between two ends.

$$V \propto I$$

6. What are ohmic and non ohmic devices

- ✓ Materials for which the current against voltage graph is a **straight line** through the origin, are said to **obey Ohm's law** and their behaviour is said to be **ohmic**.
- ✓ Materials or devices that do **not follow Ohm's law** are said to be **non-ohmic**.

7. Define electrical resistivity

It is defined as the resistance offered to current flow by a conductor of unit length having unit area of cross section.

$$\rho = \frac{RA}{L}$$

8. Define temperature coefficient of resistance

It is defined as the ratio of increase in resistivity per degree rise in temperature to its resistivity at T_0 .

$$\alpha = \frac{\Delta \rho}{\Delta T \rho_0} \quad \text{Unit: per } ^\circ\text{C}$$

9. Write a short note on superconductors

- ✓ The resistance of certain materials become zero below certain temperature.
- ✓ The materials which exhibit this property are known as superconductors.

10. What is electric power and electric energy?

Electric power: It is defined as rate at which electrical energy is delivered.

Electric energy: It is defined as capacity to do work.

11. Derive expression for power $P = VI$ in electric circuit

$$P = \frac{dU}{dt} = \frac{(V \cdot dQ)}{dt} = V \frac{dQ}{dt}$$

$$\text{Since } I = \frac{dQ}{dt} \quad P = VI$$

12. Write down various forms of expression for power in electric circuit

$$(i) P = VI$$

$$(ii) P = VI = (IR)I = I^2R$$

$$(iii) P = VI = V\left(\frac{V}{R}\right) = \frac{V^2}{R}$$

13. State Kirchhoff's first rule (Current rule or Junction rule)

- ✓ It states that the **algebraic sum of the currents** at any junction of a circuit is zero.
- ✓ It is a statement of **conservation of electric charge**.

14. Define Kirchhoff's Second rule (Voltage rule or Loop rule)

- ✓ It states that in a closed circuit the algebraic sum of the products of the current and resistance of each part of the circuit is equal to the total emf included in the circuit.
- ✓ This rule follows from the **law of conservation of energy** for an isolated system.

15.State principle of potentiometer

When a constant current flows through a wire of uniform area of cross section, then the emf of the cell is directly proportional to the balancing length of wire between two points.

$$E \propto l$$

16.What do you meant by internal resistance of a cell?

The resistance offered by electrolyte of a cell to the flow of current between its electrodes is called internal resistance of a cell.

17. Define Joule's law of heating.

$$H = I^2 R t$$

It states that the heat developed in an electrical circuit due to the flow of current varies directly as

- (i) the square of the current
- (ii) the resistance of the circuit and
- (iii) the time of flow.

18.What is Seebeck effect?

Seebeck discovered that in a closed circuit consisting of two dissimilar metals, when the junctions are maintained at different temperatures an emf (potential difference) is developed.

19.What is Thomson effect?

Thomson showed that if two points in a conductor are at different temperatures, the density of electrons at these points will differ and as a result the potential difference is created between these points. Thomson effect is also reversible.

20. What is Peltier effect?

Peltier discovered that when an electric current is passed through a circuit of a thermocouple, heat is evolved at one junction and absorbed at the other junction.

21.State the Applications of Seebeck effect.

- ✓ It is used in **thermoelectric generators** to convert waste heat into electricity in power plan.

- ✓ This effect is utilized in automobiles as automotive thermoelectric generators for **increasing fuel efficiency**.
- ✓ Seebeck effect is used in thermocouples and thermopiles to **measure the temperature difference** between the two objects.

Short Answers - Book Inside

1. Why circuit breaker is advantageous over fuse?

- ✓ Whenever there is an excessive current produced due to faulty wire connection, the circuit breaker switch opens. After repairing the faulty connection, we can close the circuit breaker switch.
- ✓ The only disadvantage with the above fuses is that once fuse wire is burnt due to excessive current, they need to be replaced

2. Define thermistor

A semiconductor with a **negative temperature coefficient of resistance** is called a thermistor. **Ex:** Germanium & silicon

3. What is carbon resistor?

Carbon resistor consists of ceramic core, on which a thin layer of crystalline carbon is deposited .

4. Why repairing the electrical connection with the wet skin is always dangerous?

- ✓ The human body contains a large amount of water which has low resistance of around $200\ \Omega$ and the dry skin has high resistance of around $500\ \text{k}\ \Omega$.
- ✓ But when the skin is wet, the resistance is reduced to around $1000\ \Omega$.
- ✓ So repairing the electrical connection with the wet skin is always dangerous.

5. Define transition (OR) critical temperature.

- ✓ The resistance of certain materials become zero below certain temperature T_c .
- ✓ This temperature is known as critical temperature or transition temperature.

6. Define Joule's heating effect.

When current flows through a resistor, some of the electrical energy delivered to the resistor is converted into heat energy and it is dissipated.

Long Answers - Book Back

1. Describe the microscopic model of current and obtain general form of Ohm's law

- ✓ Consider a conductor with area of cross section A and an electric field $\vec{E}$ applied from right to left.
- ✓ There are n electrons per unit volume in the conductor which are moving with the same drift velocity $\vec{v}_d$.
- ✓ The electrons move through a distance dx within a small interval of dt

$$v_d = \frac{dx}{dt} \quad dx = v_d dt \dots (1)$$

The electrons available in the volume of length dx = volume $\times$ number per unit volume
 $= A dx \times n \dots (2)$

Sub (1) in (2)

$$= A v_d dt \times n$$

Total charge in volume element dQ = charge $\times$ number of electrons in volume element

$$dQ = e A v_d dt \times n \dots (3)$$

$$I = \frac{dQ}{dt} \dots (4)$$

Sub (3) in (4)

$$I = \frac{neA v_d dt}{dt}$$

$$I = neA v_d$$

$$J = nev_d \dots (5) \quad \text{Since current density } J = \frac{I}{A}$$

Sub $v_d = \frac{e\tau}{m} E$ in (5)

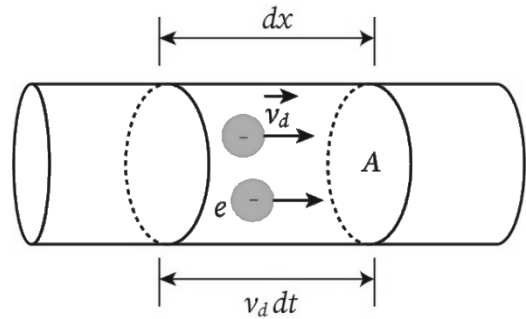
$$\vec{J} = -\frac{ne^2\tau}{m} \vec{E}$$

$$\vec{J} = -\sigma \vec{E}$$

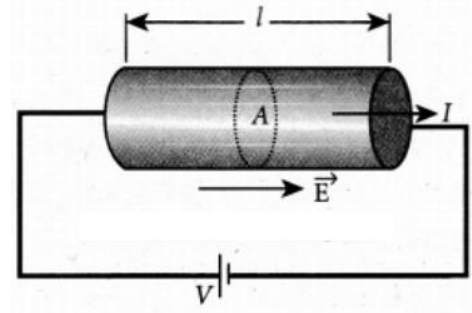
$$J = \sigma E \quad (\text{microscopic form's of ohm's law})$$

2. Obtain the macroscopic form of Ohm's law from its microscopic form and discuss its limitation

$$J = \sigma E \dots (1)$$



- ✓ Consider a segment of wire of length l and cross-sectional area A .
- ✓ When a potential difference V is applied across the wire, a net electric field is created in the wire which constitutes the current.
- ✓ Assuming electric field is uniform in the entire length of the wire, the potential difference (voltage V) can be written as



$$V = El \rightarrow E = \frac{V}{l} \text{----- (2)}$$

$$J = \frac{I}{A} \text{-----(3)}$$

Sub (2) & (3) in (1)

$$\frac{I}{A} = \sigma \frac{V}{l}$$

By rearranging above equation:

$$V = I \left(\frac{l}{\sigma A} \right)$$

$\frac{l}{\sigma A}$ - Resistance of a conductor (R)

Therefore, the macroscopic form of ohm's law can be stated as **$V = IR$**

$$R \propto l \quad R \propto \frac{1}{A}$$

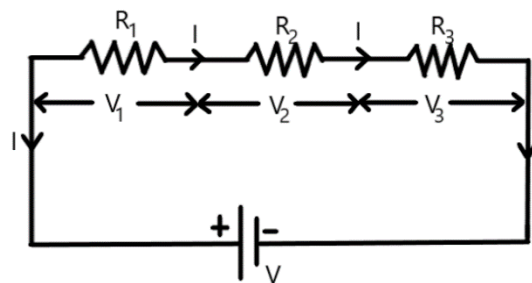
Limitations of Ohms law

- ✓ A plot of I against V for a non-ohmic material is non-linear and they do not have a constant resistance
- ✓ It is obeyed by many substances under certain conditions but it is not a fundamental law of nature
- ✓ It is applicable only for simple circuits

3.Explain the equivalent resistance of a series and parallel resistor network

Resistors in series

- ✓ R_1 , R_2 and R_3 connected in series.
- ✓ R_S is effective resistance.
- ✓ Current in each resistor is same and potential difference across resistors are different.



$$V = V_1 + V_2 + V_3$$

$$V_1 = IR_1, V_2 = IR_2, V_3 = IR_3$$

$$V = R_S I$$

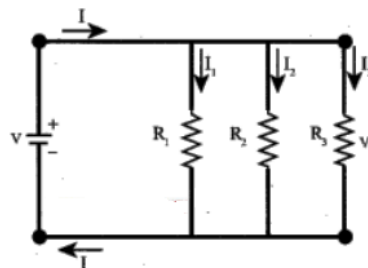
$$R_S I = R_1 I + R_2 I + R_3 I$$

$$\mathbf{R_S = R_1 + R_2 + R_3}$$

When several resistances are connected in series, the total or equivalent resistance is the sum of the individual resistances

Resistors in parallel

- ✓ R_1 , R_2 and R_3 connected in Parallel.
- ✓ R_P is effective resistance
- ✓ Potential in each resistor is same
- ✓ Current in each resistor is different



$$I = I_1 + I_2 + I_3$$

$$I = \frac{V}{R_P} \quad I_1 = \frac{V}{R_1}, \quad I_2 = \frac{V}{R_2}, \quad I_3 = \frac{V}{R_3}$$

$$\frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

When a number of resistors are connected in parallel, the sum of the reciprocal of the values of resistance of the individual resistor is equal to the reciprocal of the effective resistance of the combination.

4. Explain the determination of the internal resistance of a cell using voltmeter

- ✓ The emf of cell is measured by connecting a high resistance voltmeter across it without connecting the external resistance R .
- ✓ Since the voltmeter draws very little current for deflection, the circuit may be considered as open. Hence the voltmeter reading gives the emf of the cell.
- ✓ External resistance R is included in the circuit and current established in the circuit.
- ✓ The potential drop across the resistor R is

$$V = IR \text{ -----(1)}$$

Due to internal resistance r of the cell, the voltmeter reads a value V , which is less than the emf of cell .

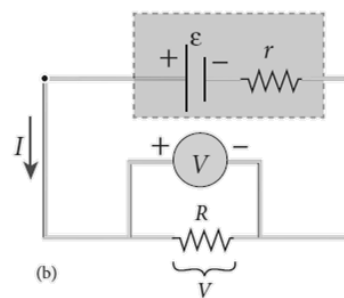
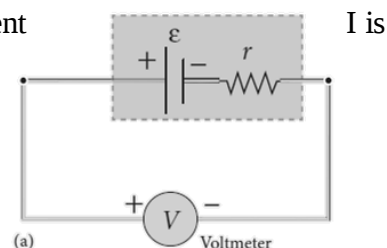
$$V = \varepsilon - Ir$$

$$Ir = \varepsilon - V \text{ -----(2)}$$

Dividing (2) by (1)

$$r = \left(\frac{\varepsilon - V}{V} \right) R$$

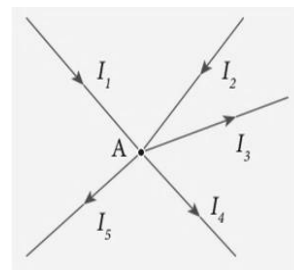
Since ε , V and R are known, internal resistance r can be determined.



5. State and explain Kirchhoff's rules

Kirchhoff's first rule (Current rule or Junction rule)

- ✓ It states that the **algebraic sum of the currents** at any junction of a circuit is **zero**.
- ✓ It is a statement of **conservation of electric charge**.
- ✓ Current entering the junction is taken as positive and current leaving the junction is taken as negative.



Applying this law to the junction A

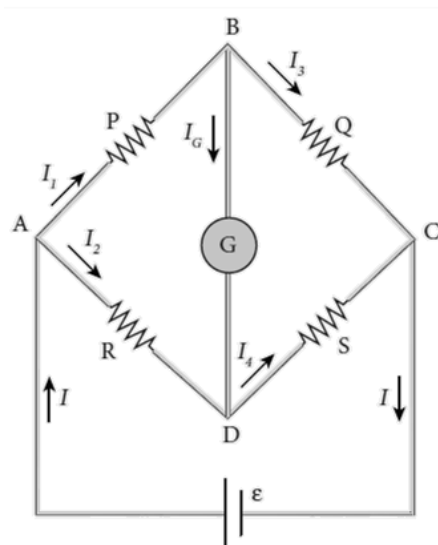
$$I_1 + I_2 - I_3 - I_4 - I_5 = 0$$

Kirchhoff's Second rule (Voltage rule or Loop rule)

- ✓ It states that in a closed circuit the **algebraic sum of the products of the current and resistance** of each part of the circuit is equal to the **total emf included in the circuit**.
- ✓ This rule follows from the law of conservation of energy for an isolated system.
- ✓ The product of current and resistance is taken as positive when the direction of the current is followed. Suppose if the direction of current is opposite to the direction of the loop, then product of current and voltage across the resistor is negative. The emf is considered positive when proceeding from the negative to the positive terminal of the cell.

6. Obtain the condition for bridge balance in Wheatstone's bridge.

- ✓ An important application of Kirchhoff's rules is the Wheatstone's bridge.
- ✓ It is used to compare resistances and also helps in determining the unknown resistance in electrical network.
- ✓ The bridge consists of four resistances P, Q, R and S connected.
- ✓ A galvanometer G is connected between the points B and D.
- ✓ The battery is connected between the points A and C. The current through the galvanometer is I_G and its resistance is G.



Applying Kirchhoff's current rule to junction B

$$I_1 - I_G - I_3 = 0 \text{ -----(1)}$$

Applying Kirchhoff's current rule to junction D,

$$I_2 + I_G - I_4 = 0 \text{ -----(2)}$$

Applying Kirchhoff's voltage rule to loop ABDA,

$$I_1 P + I_G G - I_2 R = 0 \text{ -----(3)}$$

Applying Kirchhoff's voltage rule to loop ABCDA,

$$I_1 P + I_3 Q - I_2 R - I_4 S = 0 \text{ -----(4)}$$

When points B & D are at the same potential, the bridge is said to be balanced, no current flows through galvanometer.

$$I_G = 0$$

Substituting $I_G = 0$ in (1), (2), (3), (4)

$$I_1 = I_3 \quad 0 \text{ ----- (5)}$$

$$I_2 = I_4 \quad 0 \text{ ----- (6)}$$

$$I_1 P = I_2 R \quad 0 \text{ ----- (7)}$$

Sub (5) & (6) in (4)

$$I_1 P + I_1 Q - I_2 R - I_2 S = 0$$

$$I_1 (P + Q) = I_2 (R + S)$$

$$\text{.....(8)}$$

Dividing (8) by (7)

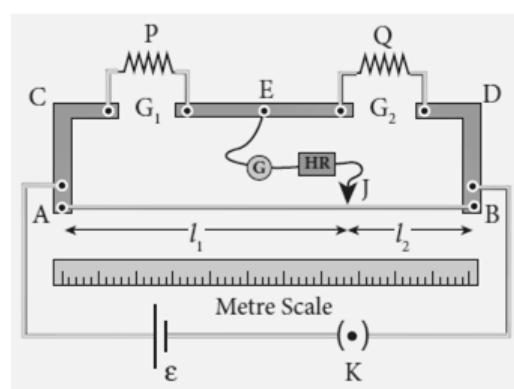
$$\frac{P+Q}{P} = \frac{R+S}{R}$$

$$1 + \frac{Q}{P} = 1 + \frac{S}{R}$$

$$\frac{P}{Q} = \frac{R}{S}$$

7. Explain the determination of unknown resistance using meter bridge

- 1) The meter bridge is another form of Wheatstone's bridge.
- 2) It consists of a uniform manganin wire AB of one meter length.
- 3) This wire is stretched along a meter scale on a wooden board between two copper strips C and D.
- 4) Between these two copper strips another copper strip E is mounted to enclose two gaps G_1 and G_2
- 5) An unknown resistance P is connected in G_1 and a standard resistance Q is connected in G_2 .
- 6) A jockey (conducting wire) is connected to the terminal E on the central copper strip through a galvanometer (G) and a high resistance (HR).
- 7) The exact position of jockey on the wire can be read on the scale. A Leclanche cell and a key (K) are connected across the ends of the bridge.
- 8) The position of the jockey on the wire is adjusted so that the galvanometer shows zero deflection. Let the point be J. The lengths AJ and JB of the bridge wire now replace the resistance R and S of the Wheatstone's bridge. Then



$$\frac{P}{Q} = \frac{R}{S} = \frac{r.AJ}{r.BJ}$$

$$\frac{P}{Q} = \frac{AJ}{JB} = \frac{l_1}{l_2}$$

$$P = Q \frac{l_1}{l_2}$$

The bridge wire is soldered at the ends of the copper strips. Due to imperfect contact, some resistance might be introduced at the contact. These are called end resistances. This error can be eliminated, if another set of readings are taken with P and Q interchanged and the average value of P is found.

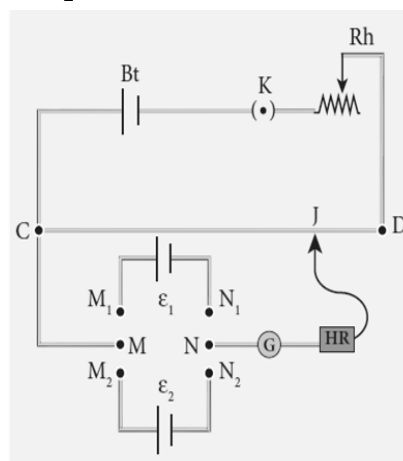
8. How the emf of two cells are compared using potentiometer?

- 1) Potentiometer wire CD is connected to a battery Bt and a key K in series. This is the primary circuit. The end C of the wire is connected to the terminal M of a DPDT (Double Pole Double Throw) switch and the other terminal N is connected to a jockey through a galvanometer G and a high resistance HR.
- 2) The cells whose emf ε_1 and ε_2 to be compared are connected to the terminals M_1 , N_1 and M_2 , N_2 of the DPDT switch.
- 3) The positive terminals of Bt, ε_1 and ε_2 should be connected to the same end C.
- 4) The DPDT switch is pressed towards M_1 , N_1 so that cell ε_1 is included in the secondary circuit and the balancing length l_1 is found by adjusting the jockey for zero deflection.
- 5) Then the second cell ε_2 is included in the circuit and the balancing length l_2 is determined.
- 6) Let r be the resistance per unit length of the potentiometer wire and I be the current flowing through the wire.

$$\varepsilon_1 = Irl_1 \dots (1) , \varepsilon_2 = Irl_2 \dots (2)$$

Dividing (1) by (2)

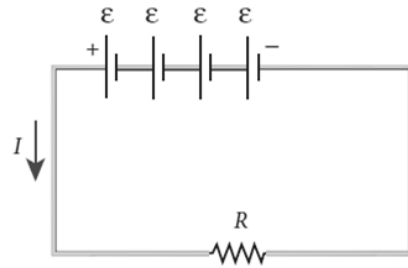
$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$$



Long Answers - Book Inside

1. Derive an expression for the current flowing in a circuit in which cells are connected in series

- ✓ In series connection, the negative terminal of one cell is connected to the positive terminal of the second cell, the negative terminal of second cell is connected to the positive terminal of the third cell and so on.
- ✓ The free positive terminal of the first cell and the free negative terminal of the last cell become the terminals of the battery.
- ✓ Suppose n cells, each of emf ε volts and internal resistance r ohms are connected in series with an external resistance R



The total emf of the battery = $n \varepsilon$

The total resistance in the circuit = $nr + R$

By Ohm's law, the current in the circuit is

$$I = \frac{\text{total emf}}{\text{total resistance}} = \frac{n\varepsilon}{nr + R} \dots\dots\dots(1)$$

Case (a) If $r \ll R$, then,

$$I = \frac{n\varepsilon}{R} \approx nI_1$$

I_1 - Current due to single cell

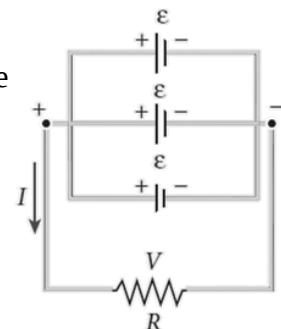
Case (b) If $r \gg R$,

$$I = \frac{n\varepsilon}{nr} \approx \frac{\varepsilon}{r}$$

1. Current due to the whole battery is the same as that due to a single cell and hence there is no advantage in connecting several cells
2. Thus series connection of cells is advantageous only when the effective internal resistance of the cells is negligibly small compared with R .

2. Derive an expression for the current flowing in a circuit in which cells are connected in parallel

- ✓ In parallel connection all the positive terminals of the cells are connected to one point and all the negative terminals to a second point. These two points form the positive and negative terminals of the battery.
- ✓ Let n cells be connected in parallel between the points A and B and a resistance R is connected between the points A and B.
- ✓ Let ε be the emf and r the internal resistance of each cell.



The equivalent internal resistance of the battery is

$$\frac{1}{r_{eq}} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} \dots\dots \frac{1}{r} \text{ (n terms)}$$

$$r_{eq} = \frac{r}{n}$$

Total resistance of the circuit = $R + \frac{r}{n}$

Current in the circuit is given by $I = \frac{\varepsilon}{R + \frac{r}{n}}$

$$I = \frac{n\varepsilon}{nR + r}$$

$$I = I = \frac{n\varepsilon}{R} \approx nI_1$$

I_1 - Current due to single cell

Case (b) If $r \ll R$,

$$I = \frac{\varepsilon}{R}$$

Case (a) If $r \gg R$,

1. From above equation that current due to the whole battery is the same as that due to a single cell.
2. Hence it is advantageous to connect cells in parallel when the external resistance is very small compared to the internal resistance of the cells.

3. Explain the any two application of Joule's heating effect

1. Electric heaters

- ✓ Electric iron, electric heater, electric toaster are some of the home appliances that utilize the heating effect of current.
- ✓ In these appliances, the heating elements are made of nichrome, an alloy of nickel and chromium.

2. Electric furnace

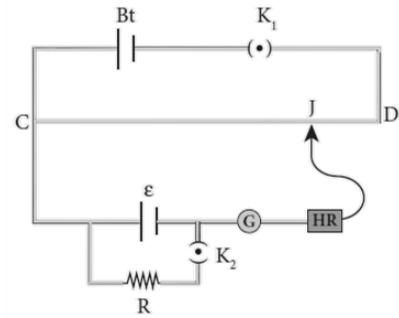
- ✓ Furnaces are used to manufacture a large number of technologically important materials such as steel, silicon carbide, quartz, gallium arsenide, etc).
- ✓ To produce temperatures up to 1500°C , molybdenum-nichrome wire wound on a silica tube is used. Carbon arc furnaces produce temperatures up to 3000°C .

3. Electrical lamp

- ✓ It consists of a tungsten filament (melting point 3380°C) kept inside a glass bulb and heated to incandescence by current. In incandescent electric lamps only about 5% of electrical energy is converted into light and the rest is wasted as heat.
- ✓ Electric discharge lamps, electric welding and electric arc also utilize the heating effect of current

4. Explain the determination of internal resistance of a cell by potentiometer

- ✓ The end C of the potentiometer wire is connected to the positive terminal of the battery Bt and the negative terminal of the battery is connected to the end D through a key K_1 . This forms the primary circuit.
- ✓ The positive terminal of the cell whose internal resistance is to be determined is also connected to the end C of the wire.
- ✓ The negative terminal of the cell is connected to a jockey through a galvanometer and a high resistance.
- ✓ A resistance box R and key K_2 are connected across the cell. With K_2 open, the balancing point J is obtained and the balancing length $CJ = l_1$ is measured.
- ✓ Since the cell is in open circuit, its emf is $\epsilon \propto l_1$
- ✓ $10\ \Omega$ resistance is included in the resistance box and key K_2 is closed.



$$I = \frac{\epsilon}{R + r} \dots\dots\dots(1)$$

The potential difference across R is

$$V = \frac{\epsilon R}{R + r}$$

When this potential difference is balanced on the potentiometer wire, let l_2 be the balancing length.

$$\frac{\epsilon R}{R + r} \propto l_2 \dots\dots\dots(2)$$

From (1) & (2)

$$\frac{R+r}{R} = \frac{l_1}{l_2} \quad r = R \left(\frac{l_1 - l_2}{l_2} \right)$$

4. Explain Thomson effect. Explain about positive and negative Thomson effect with an example

Thomson showed that if two points in a conductor are at different temperatures, the density of electrons at these points will differ and as a result the potential difference is created between these points. Thomson effect is also reversible.

Positive Thomson effect

- ✓ If current is passed through a copper bar AB which is heated at the middle point C, the point C will be at higher potential.
- ✓ This indicates that the heat is absorbed along AC and evolved along CB of the Thus heat is transferred due to the current flow in the direction of the current.
- ✓ It is called positive Thomson effect.
- ✓ Similar effect is observed in **metals like silver, zinc, and cadmium.**

Negative Thomson effect

- ✓ When the copper bar is replaced by an iron bar, heat is evolved along CA and absorbed along BC.
- ✓ Thus heat is transferred due to the current flow in the direction opposite to the direction of current.
- ✓ It is called negative Thomson effect
- ✓ Similar effect is observed in metals like **platinum, nickel, cobalt, and mercury**.

Numerical Problems Solved

1. The following graphs represent the current versus voltage and voltage versus current for the six conductors A,B,C,D,E and F.

Which conductor has least resistance which has maximum resistance?

To find:

$$R_{\text{Least}} = ? ; \quad R_{\text{max}} = ?$$

Solution:

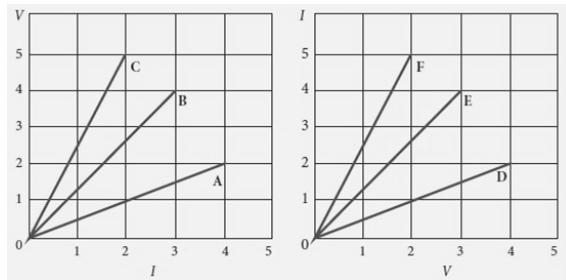
According to ohm's law $V = IR$, $R = \frac{V}{I}$

Graph 1:

$$\text{For A: slope} = R_A = \frac{\Delta V}{\Delta I} = \frac{2}{4} = 0.5\Omega$$

$$\text{For B: slope} = R_B = \frac{\Delta V}{\Delta I} = \frac{4}{3} = 1.33\Omega$$

$$\text{For C: slope} = R_C = \frac{\Delta V}{\Delta I} = \frac{5}{2} = 2.5\Omega$$



Graph 2:

$$\text{For D: } R_D = \frac{1}{\text{slope}} = \frac{\Delta V}{\Delta I} = \frac{4}{2} = 2\Omega$$

$$\text{For E: } R_E = \frac{1}{\text{slope}} = \frac{\Delta V}{\Delta I} = \frac{3}{4} = 0.75\Omega$$

$$\text{For F: } R_F = \frac{1}{\text{slope}} = \frac{\Delta V}{\Delta I} = \frac{2}{5} = 0.4\Omega$$

Least Resistance, $R_F = 0.4\Omega$

Maximum Resistance $R_C = 2.5\Omega$

2. Lightning is very good example of natural current. In typical lightning, there is 10^9 J energy transfer across the potential difference of 5×10^7 V during a time interval of 0.2 s. Using this information, estimate the following quantities (a) total amount of charge transferred between cloud and ground (b) the current in the lightning bolt (c) the power delivered in 0.2 s.

Given:

$$W = 10^9 \text{J}, \quad V = 5 \times 10^7 \text{volt} \quad t = 0.2 \text{ s} = 2 \times 10^{-1} \text{s} \quad q = ?, I = ?, P = ?$$

Solution:



(i) Total amount of charge transferred

$$q = \frac{w}{V} = \frac{10^9}{5 \times 10^7} = 0.2 \times 10^2 = 20 \text{ C}$$

(ii) Current in the lightning bolt

$$I = \frac{q}{t} = \frac{20}{2 \times 10^{-1}} = 100 \text{ A}$$

(iii) Power delivered in 0.2 second,

$$P = VI = 5 \times 10^7 \times 10^2 \\ = 5 \times 10^9 \text{ W}$$

$$P = 5 \text{ GW}$$

3. A copper wire of 10^{-6} m^2 area of cross section, carries a current of 2 A. If the number of electrons per cubic meter is 8×10^{28} , calculate the current density and average drift velocity.

Given:

$$A = 10^{-6} \text{ m}^2, I = 5 \text{ A}, n = 8 \times 10^{28}, J = ?, v_d = ?$$

Solution:

$$(i) J = \frac{I}{A} = \frac{2}{10^{-6}} = 2 \times 10^6 \text{ A m}^{-2}$$

$$(ii) J = nev_d$$

$$v_d = \frac{J}{ne} = \frac{2 \times 10^6}{8 \times 10^{28} \times 1.6 \times 10^{-19}} \\ v_d = \frac{10^{-3}}{6.4} = 1.56 \times 10^{-4} \text{ m s}^{-1}$$

4. The resistance of a nichrome wire at 20°C is 10Ω . If its temperature coefficient of resistance is $0.004/^\circ\text{C}$, find its resistance at boiling point of water. Comment on the result.

Given:

$$R_0 = 10 \Omega, T_0 = 20^\circ\text{C}, T = 100^\circ\text{C}, \alpha = 0.004/^\circ\text{C}, R_{100} = ?,$$

Solution:

$$R_t = R_0[1 + \alpha(T - T_0)]$$

$$R_{100} = 10[1 + 0.004 \times 80]$$

$$= 10[1 + 0.32]$$

$$= 10 \times 1.32 = 13.2 \Omega$$

$$R_{100} = 13.2 \Omega$$

As temperature increases, the resistance of wire also increases

5. The rod given in the figure is made up of two different materials. Both have square cross sections of 3 mm side. The resistivity of the first material is $4 \times 10^{-3} \Omega\text{m}$ and it is 25 cm long while second material has resistivity of $5 \times 10^{-3} \Omega\text{m}$ and is of 70 cm long. What is the resistivity of rod between its ends?



Given:

$$\rho_1 = 4 \times 10^{-3} \Omega \text{ m}, l_1 = 25 \text{ cm}$$

$$\rho_2 = 5 \times 10^{-3} \Omega \text{ m}, l_2 = 70 \text{ cm},$$

$$\text{Side length} = 3 \text{ mm} = 3 \times 10^{-3} \text{ m}$$

$$\text{Area} = (3 \times 10^{-3} \text{ m})^2 = 9 \times 10^{-6} \text{ m}^2$$

Solution:

$$R_s = R_1 + R_2 \rightarrow (1)$$

$$R_1 = \frac{\rho_1 l_1}{A} = \frac{4 \times 10^{-3} \times 25 \times 10^{-2}}{9 \times 10^{-6}}$$

$$= \frac{1000}{9} \Omega$$

$$R_2 = \frac{\rho_2 l_2}{A} = \frac{5 \times 10^{-3} \times 70 \times 10^{-2}}{9 \times 10^{-6}}$$

$$= \frac{3500}{9} \Omega$$

$$(1) \rightarrow R_s = \frac{1000}{9} + \frac{3500}{9} = \frac{4500}{9} = 500 \Omega$$

$$\therefore \text{Resistance } R_s = 500 \Omega$$

6. Three identical lamps each having a resistance R are connected to the battery of emf as shown in the figure.

Suddenly the switch S is closed.

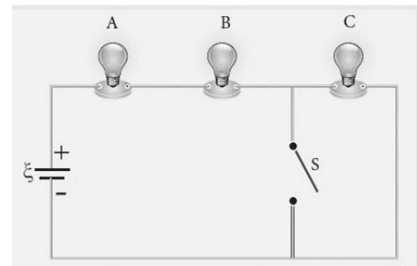
(a) Calculate the current in the circuit when S is open and closed

(b) What happens to the intensities of the bulbs A, B and C.

(c) Calculate the voltage across the three bulbs when S is open and closed

(d) Calculate the power delivered to the circuit when S is opened and closed

(e) Does the power delivered to the circuit decreases, increases or remain same?

**Solution**

(a) Current

According to ohm's law, $V = IR$

$$\varepsilon = V$$

$$R_1 = R_2 = R_3 = R$$

Three lamps are connected in series

$$R_s = R_1 + R_2 + R_3 = R + R + R = 3R$$

When switch is open,

$$I = \frac{V}{R_s} = \frac{\varepsilon}{3R}$$

When switch is closed, then no current flow through lamp 'c'

$$I = \frac{\varepsilon}{2R}$$

(b) Intensities of A,B,C:

(i) When switch is open. Three lamps are in series combination so there is no change in intensity. So all bulbs having equal intensities.

(ii) When switch is closed

Bulb A and B only in series so the intensity across A and B increases and both having equal intensities.

The bulb 'C' in parallel, hence no current flow through it. So bulb 'C' will not glow

(c) Voltage:

(i) When switch is open in series

combination, current will be same.

$$I = \frac{\varepsilon}{3R}$$

$$V_A = IR = \frac{\varepsilon}{3R} \times R = \frac{\varepsilon}{3}$$

$$V_B = IR = \frac{\varepsilon}{3R} \times R = \frac{\varepsilon}{3}$$

$$V_C = IR = \frac{\varepsilon}{3R} \times R = \frac{\varepsilon}{3}$$

(ii) When switch is closed,

$$I = \frac{\varepsilon}{2R}$$

$$V_A = IR = \frac{\varepsilon}{2R} \times R = \frac{\varepsilon}{2}$$

$$V_B = IR = \frac{\varepsilon}{2R} \times R = \frac{\varepsilon}{2}$$

Bulb 'C' is in parallel,

$$\therefore I = 0$$

$$V_C = IR = 0 \times R = 0$$

(d) Power:

(i) When switch is open

$$P_A = V_A I_A = \frac{\varepsilon}{3} \times \frac{\varepsilon}{3R} = \frac{\varepsilon^2}{9R}$$

Since switch is opened, Power is same.

$$P_A = P_B = P_C = \frac{\varepsilon^2}{9R}$$

(ii) When switch is closed:

$$I = \frac{\varepsilon}{2R}$$

$$P_A = V_A I_A$$

$$P_A = \frac{\varepsilon}{2} \times \frac{\varepsilon}{2R} = \frac{\varepsilon^2}{4R}$$

$$P_B = V_B I_B$$

$$P_B = \frac{\varepsilon}{2} \times \frac{\varepsilon}{2R} = \frac{\varepsilon^2}{4R}$$

Bulb 'C' is in parallel,

$$V_C = 0, I_C = 0$$

$$P_C = V_C I_C$$

$$P_C = 0 \times 0 = 0$$

$\therefore$ Total power will increase.

7. An electronics hobbyist is building a radio which requires 150 Ω in her circuit, but she has only 220 Ω , 79 Ω and 92 Ω resistors available. How can she connect the available resistors to get desired value of resistance?

Given:

Resistance required, $R = 150 \Omega$, $R_1 = 220 \Omega$, $R_2 = 79 \Omega$, $R_3 = 92 \Omega$

Solution:

For getting 150 Ω as a resultant value,

R_1 and R_2 will connect in parallel and series with R_3 .

R_1 and R_2 are connected in parallel,

$$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{220 \times 79}{220 + 79}$$

$$R_p = \frac{17380}{299}$$

$$R_p = 58 \Omega$$

Now,

R_3, R_p are in series,

$$R_s = R_p + R_3 = 58 + 92 = 150 \Omega$$

$$\therefore R_s = 150 \Omega$$

**Parallel combination of 220Ω and 79Ω
in series with 92Ω**

8. A cell supplies a current of 0.9 A through a 2Ω resistor and a current of 0.3 A through a 7Ω resistor. Calculate the internal resistance of the cell.

Given:

$$I_1 = 0.9 \text{ A}, \quad I_2 = 0.3 \text{ A}, \quad R_1 = 2 \Omega, \quad R_2 = 7 \Omega, \quad r = ?$$

Solution:

$$I_1 = \frac{\varepsilon}{R_1 + r}, \quad \varepsilon = I_1(R_1 + r) \rightarrow (1)$$

$$I_2 = \frac{\varepsilon}{R_2 + r}, \quad \varepsilon = I_2(R_2 + r) \rightarrow (2)$$

From (1) and (2) $\rightarrow I_1(R_1 + r) = I_2(R_2 + r)$

$$I_1 R_1 + I_1 r = I_2 R_2 + I_2 r$$

$$r[I_1 - I_2] = I_2 R_2 - I_1 R_1$$

$$\begin{aligned} r &= \frac{I_2 R_2 - I_1 R_1}{[I_1 - I_2]} \\ &= \frac{0.3 \times 7 - 0.9 \times 2}{0.9 - 0.3} \\ &= \frac{2.1 - 1.8}{0.6} \end{aligned}$$

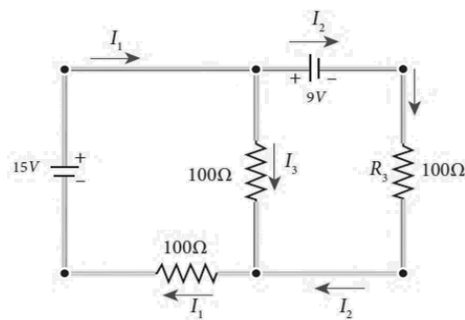
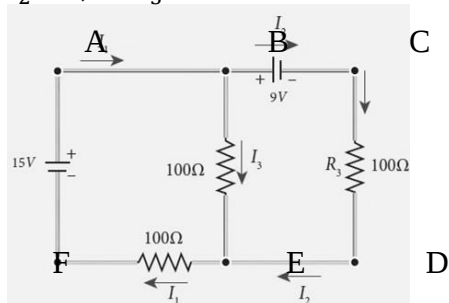
$$r = \frac{0.3}{0.6} = 0.5 \Omega$$

$$r = 0.5 \Omega$$

9. Calculate the currents in the following circuit.

To find

$$I_1 = ?, \quad I_2 = ?, \quad I_3 = ?$$



Applying Kirchoff's current rule at junction B,

$$I_1 - I_2 - I_3 = 0, \quad I_3 = I_1 - I_2 \rightarrow (1)$$

Applying Kirchoff's voltage rule for closed path ABEFA,

$$100 I_1 + 100 I_3 = 15$$

$$100 I_1 + 100(I_1 - I_2) = 15$$

$$100 I_1 + 100 I_1 - 100 I_2 = 15$$

$$200 I_1 - 100 I_2 = 15 \rightarrow (2)$$

Applying Kirchoff's voltage rule for closed path BCDEB,

$$100 I_2 - 100 I_3 = -9$$

$$100 I_2 - 100(I_1 - I_2) = -9$$

$$100 I_2 - 100 I_1 + 100 I_2 = -9$$

$$200 I_2 - 100 I_1 = -9$$

$$-100 I_1 + 200 I_2 = -9 \rightarrow (3)$$

$$(2) \Rightarrow \quad 200 I_1 - 100 I_2 = 15$$

$$(3) \times 2 \Rightarrow -200 I_1 + 400 I_2 = -19$$

$$\begin{array}{ccc} (+) & (+) & (+) \end{array}$$

$$300 I_2 = -3$$

$$I_2 = -\frac{1}{100} = -1 \times 10^{-2}$$

$$\Rightarrow I_2 = -0.01 \text{ A}$$

Sub I_2 value in (2)

$$(2) \Rightarrow 200 I_1 - 100 \times -\frac{1}{100} = 15$$

$$200 I_1 + 1 = 15$$

$$200 I_1 = 14 ,$$

$$I_1 = \frac{7}{100}$$

$$I_1 = 0.07 \text{ A}$$

$$\begin{aligned} (1) \Rightarrow I_3 &= I_1 - I_2 \\ &= 0.07 - (-0.01) \end{aligned}$$

$$I_3 = 0.08 \text{ A}$$

10. A potentiometer wire has a length of 4 m and resistance of 20Ω . It is connected in series with resistance of 2980Ω and a cell of emf 4 V. Calculate the potential along the wire.

Given: $l = 4 \text{ m}$, resistance, $r = 20 \Omega$, $r' = 2980 \Omega$, $\varepsilon = 4\text{V}$, $E = ?$

Solution:

Effective resistance for two resistors in series combination

$$R_s = r + r' = 20 + 2980 \Omega$$

$$R_s = 3000 \Omega$$

$$I = \frac{\varepsilon}{R} = \frac{4}{3000} \text{ A}$$

Potential drop across the wire,

$$V = Ir = \frac{4}{3000} \times 20 = \frac{4}{150} \text{ volt}$$

∴ Potential gradient,

$$E = \frac{V}{l} = \frac{4}{150} \times \frac{1}{4}$$

$$E = \frac{1}{15 \times 10} = \frac{10 \times 10^{-2}}{15} = 0.66 \times 10^{-2} \text{ Vm}^{-1}$$

$$E = 0.66 \times 10^{-2} \text{ Vm}^{-1}$$

11. Determine the current flowing through the galvanometer (G) as shown in the figure.

Solution:

Apply Kirchoff's current rule at junction P,

$$I - I_1 - I_2 = 0$$

$$I - I_1 = I_2 \rightarrow (1)$$

Apply Kirchoff's voltage rule for closed path, PQSP,

$$5 I_1 + 10 I_g - 15 I_2 = 0$$

$$\text{From (1) } 5 I_1 + 10 I_g - 15(I - I_1) = 0$$

$$5 I_1 + 10 I_g - 15 I + 15 I_1 = 0$$

$$I = 2A,$$

$$20 I_1 + 10 I_g - 15 \times 2 = 0$$

$$20 I_1 + 10 I_g = 30 \rightarrow (2)$$

Apply Kirchoff's voltage rule for closed path, QRSP,

$$10(I_1 - I_g) - 20(I_2 + I_g) - 10 I_g = 0$$

$$10 I_1 - 10 I_g - 20 I_2 - 20 I_g - 10 I_g = 0$$

$$\text{From (1) } 10 I_1 = 40 I_g - 20(I - I_1) = 0$$

$$10 I_1 - 40 I_g - 20 I + 20 I_1 = 0$$

$$I = 2A,$$

$$30 I_1 - 40 I_g - 20 \times 2 = 0$$

$$30 I_1 - 40 I_g = 40 \rightarrow (3)$$

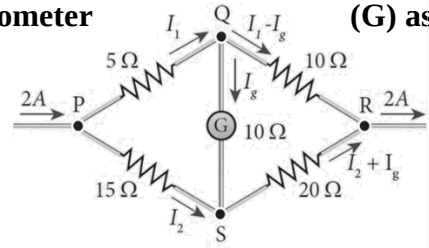
$$(2) \times 3 \quad 60 I_1 + 30 I_g = 90$$

$$(3) \times 2 \quad 60 I_1 - 80 I_g = 80$$

$$\begin{array}{r} (-) \quad (+) \quad (-) \\ \hline \end{array}$$

$$110 I_g = 10$$

$$I_g = \frac{1}{11} \text{ A}$$



12. Two cells each of 5V are connected in series across a 8 Ω resistor and three parallel resistors of 4 Ω, 6 Ω and 12 Ω. Draw a circuit diagram for the above arrangement.

Calculate

i) the current drawn from the cell (ii) current through each resistor

To find: I=?

Solution:

$R_1 = 4 \Omega$, $R_2 = 6 \Omega$, $R_3 = 12 \Omega$ are connected in parallel,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$= \frac{1}{4} + \frac{1}{6} + \frac{1}{12}$$

$$\frac{1}{R_p} = \frac{3 + 2 + 1}{12} = \frac{6}{12} = \frac{1}{2} \Omega$$

$$\therefore R_p = 2 \Omega$$

Now, 8Ω and 2 Ω resistors are in series

$$R_s = R + R_p = 8 + 2 = 10$$

$$\therefore R_s = 10 \Omega$$

Two cells are connected in series,

$$\varepsilon = \varepsilon_1 + \varepsilon_2 = 5 + 5 = 10 \text{ volt}$$

Current drawn from each cell,

$$I = \frac{\varepsilon}{R_s} = \frac{10}{10} = 1 \text{ A}$$

Potential difference through 8Ω resistor is,

$$V = IR$$

$$V = 1 \times 8 = 8 \text{ volt.}$$

Potential through 2Ω (net resistance in parallel)

$$V = IR = 1 \times 2 = 2 \text{ V}$$

(i) Current through 8Ω resistor,

$$I = \frac{V}{R} = \frac{8}{8} = 1 \text{ A}; \quad I = 1 \text{ A}$$

(ii) Current through

4Ω, 6 Ω, 12 Ω resistor,

$$R = 4 \Omega, \quad I = \frac{V}{R} = \frac{2}{4} = 0.5 \text{ A}$$

$$R = 6 \Omega, \quad I = \frac{V}{R} = \frac{2}{6} = 0.33 \text{ A}$$

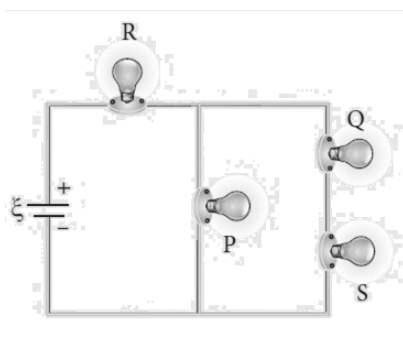
$$R = 12 \Omega, \quad I = \frac{V}{R} = \frac{2}{12} = 0.166 \text{ A}$$

13. Four light bulbs P, Q, R, S are connected in a circuit of unknown arrangement. When each bulb is removed one at a time and replaced, the following behaviour is observed.

Given:

	P	Q	R	S
P removed	*	ON	ON	ON
Q removed	ON	*	ON	OFF
R removed	OFF	OFF	*	OFF
S removed	ON	ON	ON	*

Solution:



14. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63 cm, what is the emf of the second cell?

Given: $\varepsilon_1 = 1.25 \text{ V} = \frac{5}{4} \text{ V}$, $\varepsilon_2 = ?$, $l_1 = 35 \times 10^{-2} \text{ m}$, $l_2 = 63 \times 10^{-2} \text{ m}$

Solution: $\frac{\varepsilon_2}{\varepsilon_1} = \frac{l_2}{l_1}$;

$$\varepsilon_2 = \varepsilon_1 \times \frac{l_2}{l_1}$$

$$\varepsilon_2 = \frac{5}{4} \times \frac{63 \times 10^{-2}}{35 \times 10^{-2}}$$

$$= \frac{9}{4} = 2.25 \text{ V}$$

$$\varepsilon_2 = 2.25 \text{ volt}$$

UNIT - 3 MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT**Important Questions**

Two Marks	
Book Back	Book inside
1.State Coulomb's inverse law 2.State Ampere's circuital law 3.What is meant by hysteresis? 4.What is resonance condition in cyclotron? 5.State Fleming's left hand rule 6.How is a galvanometer converted into (i) an ammeter (ii) voltmeter 7. Define Magnetic declination and inclination 8. Define ampere	1.Define Meissner effect. 2. Define Tangent law 3.Define Curie's law 4.Define Curie-Weiss law. 5. What are Limitations of cyclotron 6. How will you increase the current sensitivity of a galvanometer
Three Marks	
1.State Biot-Savart's law 2.Compare dia, para & ferro magnetism 3.Find the magnetic induction due to a straight conductor using ampere's circuital law 4.Give an account of magnetic Lorentz force	1.Write about properties of Magnetic field lines 2.What are Applications of hysteresis loop
Five marks	
1.Deduce the relation for the magnetic induction at a point due to an infinitely long straight conductor carrying current 2.Obtain a relation for the magnetic induction at a point along the axis of a circular coil carrying current 3.Discuss the working of cyclotron in detail 4.Calculate the magnetic field inside and outside of the long solenoid using Ampere's circuital law 5. Derive an expression for Force on a current carrying conductor placed in a magnetic field 6. Derive an expression for Force acting between two long parallel current carrying conductors 7. Discuss the conversion of galvanometer into an ammeter and also a voltmeter	

Important Formulae and Units

1. **Magnetic flux,**

$\phi_B = \vec{B} \cdot \vec{A} = BA \cos \theta$, Dimensional formula: $[ML^2T^{-2}A^{-1}]$ Unit: Weber

2. **Coulomb's inverse square Law:**

$$F = \frac{\mu_0}{4\pi} \frac{qM_A qM_B}{r^2} \text{ (Magnitude form)}$$

3. Biot- Savart Law, $dB = \frac{\mu_0}{4\pi} \frac{I dl \sin \theta}{r^2}$

4. Magnetic field due to an infinitely long straight conductor, $\vec{B} = \frac{\mu_0 I}{2\pi a} \hat{n}$

5. Magnetic field due to an axis of a current carrying circular coil,

$$\vec{B} = \frac{\mu_0 I}{2\pi a} \frac{R^2}{(R^2 + Z^2)^{3/2}} \hat{K}$$

6. Magnetic dipole moment of revolving electron, $\mu_L = -\frac{evR}{2} \Rightarrow \vec{\mu}_L = -\frac{e}{2m} \vec{L}$

7. **Bohr magneton**

$$\mu_0 = \frac{eh}{4\pi m} = 9.27 \times 10^{-24} \text{ Am}^2$$

8. Ampere's Circuital law,

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}}$$

9. Magnetic field due to straight solenoid,

$$B = \mu_0 nI \Rightarrow n = \frac{N}{L}$$

10. Magnetic field inside a toroidal solenoid,

$$B_s = \mu_0 nI \Rightarrow n = \frac{N}{2\pi r}$$

11. Lorentz force, $\vec{F}_m = q(\vec{v} \times \vec{B})$ in magnitude, $F_m = qvB \sin \theta$

12. Force on a current- carrying conductor in a magnetic field $F = BIl \sin \theta$

13. Force between two parallel current – carrying wires: $\frac{\vec{F}}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \hat{j}$

14. Torque on a current loop in a magnetic field, $\tau = NIBA \sin \theta = \vec{P}_m \times \vec{B}$

15. In a moving coil galvanometer

(i) Current, $I = \frac{K}{NBA} \theta$

(ii) Deflection produced, $\theta = \frac{NBA}{K} I$

(iii) Current Sensitivity $I_s = \frac{\theta}{I} = \frac{NBA}{K}$

(iv) Voltage sensitivity $V_s = \frac{\theta}{IR_g} = \frac{NBA}{KR_g}$

16. For conversion of a galvanometer into an ammeter, the shunt resistance,

$$S = \frac{I_g}{(I - I_g)} R_g \Rightarrow I_g = \left(\frac{S}{S + R_g} \right) I$$

17. Resistance of an ammeter, $R_a = \frac{R_g S}{R_g + S}$

18. **Gyromagnetic ratio:**

$$\frac{\mu_L}{L} = 8.78 \times 10^{10} \text{ CKg}^{-1}$$

19. Resultant magnetic field of the earth $B = \sqrt{B_H^2 + B_V^2}$

20. Horizontal component & Vertical

component: $B_H = B_E \cos I$ & $B_V = B_E \sin I$

21. Ratio of Magnetic length to geometric

length: $\frac{\text{Magnetic length}}{\text{geometric length}} = \frac{5}{6} = 0.833$

23. Current when deflection θ , radius R and

magnetic field B_H given $I = \frac{2RB_H}{\mu_0 N} \tan \theta$

24. **Magnetic susceptibility**

$$\chi_m = \frac{\text{intensity of magnetisation}}{\text{magnetising field}} = \frac{\vec{M}}{\vec{H}}$$

25. Magnetic dipole moment of bar magnet:

$$p_m = 2q_m l$$

26. Unit of Pole strength q_m : NT^{-1} Or Am Dimensional formula: $M^0 L T^0 A$

27. One tesla = $1 \text{ NA}^{-1}\text{m}^{-1}$

28. 1 weber = 10^8 Maxwell

29. Unit of magnetic flux density : Wb m^{-2} Or tesla (T)

30. In equator: Horizontal component is maximum and Vertical component is zero

31. At poles: Horizontal component is zero and Vertical component is maximum

Textbook One Marks Solved

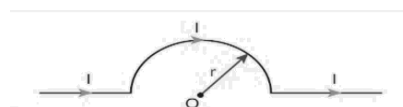
1. The magnetic field at the center O of the following current loop is

(a) $\frac{\mu_0 I}{4r} \otimes$

(b) $\frac{\mu_0 I}{4r} \odot$

(c) $\frac{\mu_0 I}{2r} \otimes$

(d) $\frac{\mu_0 I}{2r} \odot$



Hint: Magnetic field at the centre of a circular loop $B = \frac{\mu_0 I}{2\pi R}$

From the figure, $R = \frac{2r}{\pi}$

$B = \frac{\mu_0 I}{4r}$ According to right hand thumb rule field B acts inwards

Answer: (a) $\frac{\mu_0 I}{4r} \otimes$

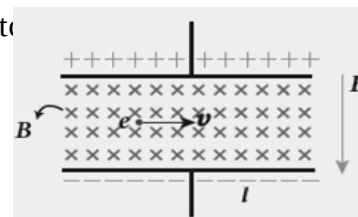
2. An electron moves straight inside a charged parallel plate capacitor of uniform charge density σ . The time taken by the electron to cross the parallel plate capacitor when the plates of the capacitor are kept under constant magnetic field of induction $\vec{E}$ is

a) $\epsilon_0 \frac{eIB}{\sigma}$

(b) $\epsilon_0 \frac{IB}{\sigma I}$

(c) $\epsilon_0 \frac{IB}{\sigma e}$

(d) $\epsilon_0 \frac{IB}{\sigma}$



Hint: velocity $v = \frac{1}{t}$; velocity $v = \frac{E}{B}$; $E = \frac{\sigma}{\epsilon_0}$

$$\frac{1}{t} = \frac{E}{B}$$

$$t = \epsilon_0 \frac{IB}{\sigma}$$

Answer: (d) $\epsilon_0 \frac{IB}{\sigma}$

3. A particle having mass m and charge q accelerated through a potential difference V. Find the force experienced by a particle having mass m and charge q accelerated through a potential difference V when it is kept under perpendicular magnetic field $\vec{B}$ is

(a) $\sqrt{\frac{2q^3 BV}{m}}$

(b) $\sqrt{\frac{2q^3 B^2 V}{2m}}$

(c) $\sqrt{\frac{2q^3 B^2 V}{m}}$

(d) $\sqrt{\frac{2q^3 BV}{m^3}}$

Hint: Kinetic energy: $\frac{1}{2}mv^2 = qV$; $v = \sqrt{\frac{2qV}{m}}$

$$F = Bqv = Bq\sqrt{\frac{2qV}{m}}$$

Answer: (c) $\sqrt{\frac{2q^3B^2V}{m}}$

4. A circular coil of radius 5 cm and 50 turns carries a current of 3 ampere. The magnetic dipole moment of the coil is

- (a) 1.0 A m² (b) 1.2 A m² (c) 0.5 A m² (d) 0.8 A m²

Hint: $P_m = NIA$; Where $N = 50$, $I = 3$, $r = 5\text{cm} = 5 \times 10^{-2}$, $A = \pi r^2$

$$P_m = 1.2 \text{ amp} - \text{m}^2$$

Answer: (b) 1.2 amp – m²

5. A thin insulated wire forms a plane spiral of $N = 100$ tight turns carrying a current $I = 8$ m A (milli ampere). The radii of inside and outside turns are $a = 50$ mm and $b = 100$ mm respectively. The magnetic induction at the centre of the spiral is

- (a) 5 μT (b) 7 μT (c) 8 μT (d) 10 μT

Hint: $dB = \int_a^b \frac{\mu_0 NI}{2x} dx = \frac{\mu_0 NI}{2a} \ln \frac{b}{a}$

Answer: (b) 7 μT

6. Three wires of equal lengths are bent in the form of loops. One of the loops is circle, another is a semi-circle and the third one is a square. They are placed in a uniform magnetic field and same electric current is passed through them. Which of the following loop configuration will experience greater torque ?

- (a) circle (b) semi-circle (c) square (d) all of them

Hint: torque (τ) $\propto$ area (A)

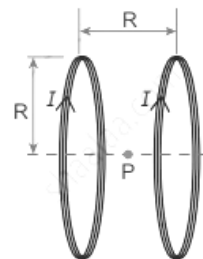
Area of circle (πr^2) > Area of square (r^2) > Area of semicircle ($\frac{1}{2}$) πr^2

Answer: (a) circle

7. Two identical coils, each with N turns and radius R are placed coaxially at a distance R as shown in the figure. If I is the current passing through the loops in the same direction, then the magnetic field at a point P which is at exactly $R/2$ at distance between two coils is

- (a) $\frac{8N\mu_0 I}{\sqrt{5}R}$ (b) $\frac{8N\mu_0 I}{5^{3/2}R}$
(c) $\frac{8N\mu_0 I}{5R}$ (d) $\frac{4N\mu_0 I}{\sqrt{5}R}$

Hint: $B_1 = \frac{\mu_0 I}{2} \frac{R^2}{(R^2 + Z^2)^{3/2}}$ Here $Z = \frac{3}{2}$



$$B_1 = \frac{\mu_0 I}{2} \frac{8R^2}{R^3(5)^{3/2}} \text{ which is equal to } B_2$$

Total field at P which is equal to $B_1 + B_2$

Answer: (b) $\frac{8N\mu_0 I}{5^{3/2}R}$

8. A wire of length l carries a current I along the Y direction and magnetic field is given by

$\vec{B} = \frac{\beta}{\sqrt{3}}(\hat{i} + \hat{j} + \hat{k})$ The magnitude of Lorentz force acting on the wire is

(a) $\sqrt{\frac{2}{3}} BIl$ (b) $\sqrt{\frac{1}{\sqrt{3}}} \beta Il$ (c) $\sqrt{2} \beta Il$ (d) $\sqrt{\frac{1}{2}} \beta Il$

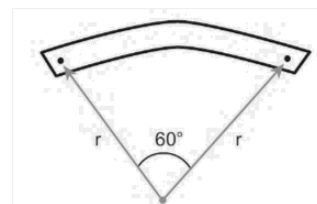
Hint: $\vec{B} = \frac{\beta}{\sqrt{3}}(\hat{i} + \hat{j} + \hat{k})$ $F = (\vec{I} \times \vec{B}) = I\vec{j} \times \frac{\beta}{\sqrt{3}}(\hat{i} + \hat{j} + \hat{k})$ $F = \frac{\beta Il}{\sqrt{3}}(\hat{j} \times \hat{i} + \hat{j} \times \hat{j} + \hat{j} \times \hat{k})$

$$F = \frac{\beta Il}{\sqrt{3}}(\hat{k} + 0 + \hat{i}) = \frac{\beta Il}{\sqrt{3}}\sqrt{1+1} = \sqrt{\frac{2}{3}} \beta Il$$

Answer: (a) $\sqrt{\frac{2}{3}} \beta Il$

9. A bar magnet of length l and magnetic moment M is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be

(a) p_m (b) $\frac{3}{\pi} p_m$
(c) $\frac{2}{\pi} p_m$ (d) $\frac{1}{2} p_m$



Hint: Magnetic moment $p_m = q_m l$

After bending its magnetic moment $p_{m\text{new}} = q_m l_{\text{new}}$

$$l_{\text{new}} = 2r \sin 30^\circ = r$$

arc length = radius $\times \theta$

$$l_{\text{new}} = \frac{3l}{\pi}$$

After bending its magnetic moment $p_{m\text{new}} = q_m \frac{3l}{\pi}$

Answer: (b) $\frac{3}{\pi} p_m$

10. A non-conducting charged ring of charge q , mass m and radius r is rotated with constant angular speed ω . Find the ratio of its magnetic moment with angular momentum is

(a) $\frac{q}{m}$ (b) $\frac{2q}{m}$ (c) $\frac{q}{2m}$ (d) $\frac{q}{4m}$

Hint: Magnetic moment; $\mu_L = I.A$; $\mu_L = \frac{q}{T} \pi r^2$; $T = \frac{2\pi}{\omega}$

Angular momentum $L = mr^2\omega$

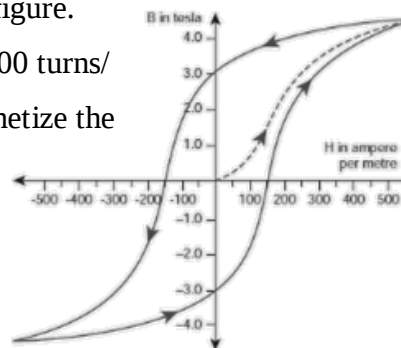
$$\frac{\mu_L}{L} = \frac{q}{2m}$$

Answer: (c) $\frac{q}{2m}$

11. The BH curve for a ferromagnetic material is shown in the figure.

The material is placed inside a long solenoid which contains 1000 turns/cm. The current that should be passed in the solenoid to demagnetize the ferromagnet completely is

- (a) 1.00 mA (b) 1.25 mA
(c) 1.50 mA (d) 1.75 mA



Hint: $H = nI$ Given $n = \frac{1000 \text{ turns}}{\text{cm}}$

$H = 150$ (see the graph)

$$I = \frac{H}{n} = 1.50 \times 10^{-3}$$

Answer: (c) 1.50 mA

12. Two short bar magnets have magnetic moments 1.20 Am^2 and 1.00 Am^2 respectively.

They are kept on a horizontal table parallel to each other with their north poles pointing towards the south. They have a common magnetic equator and are separated by a distance of 20.0 cm. The value of the resultant horizontal magnetic induction at the mid-point O of the line joining their centers is (Horizontal components of Earth's magnetic induction is $3.6 \times 10^{-5} \text{ Wb m}^{-2}$)

- (a) $3.60 \times 10^{-5} \text{ Wb m}^{-2}$ (b) $3.5 \times 10^{-5} \text{ Wb m}^{-2}$
(c) $2.56 \times 10^{-4} \text{ Wb m}^{-2}$ (d) $2.2 \times 10^{-4} \text{ Wb m}^{-2}$

Hint: $P_{m1} = 1.20, P_{m2} = 1, r = \frac{20}{2} = 10^{-1} \text{ m}, B_H = 3.6 \times 10^{-5}$

$$\text{Resultant magnetic field} = B_1 + B_2 + B_H = \frac{\mu_0}{4\pi r^3} P_{m1} + \frac{\mu_0}{4\pi r^3} P_{m2} + 3.6 \times 10^{-5}$$

Answer: (c) $2.56 \times 10^{-4} \text{ Wb m}^{-2}$

13. The vertical component of Earth's magnetic field at a place is equal to the horizontal component. What is the value of angle of dip at this place?

- (a) 30° (b) 45° (c) 60° (d) 90°

Hint: $B_V = B_H; \tan \theta = \frac{B_V}{B_H} = 1; \theta = 45^\circ \text{ Or } \frac{\pi}{4}$

Answer: (b) 45°

14. A flat dielectric disc of radius R carries an excess charge on its surface. The surface charge density is σ . The disc rotates about an axis perpendicular to its plane passing through the center with angular velocity ω . Find the magnitude of the torque on the disc if it is placed in a uniform magnetic field whose strength is B which is directed perpendicular to the axis of rotation

- (a) $\frac{1}{4}\sigma\omega\pi BR$ (b) $\frac{1}{4}\sigma\omega\pi BR^2$ (c) $\frac{1}{4}\sigma\omega\pi BR^3$ (d) $\frac{1}{4}\sigma\omega\pi BR^4$

Hint : $\tau = BAI = B \frac{Q}{T} \times \frac{A}{2} = B \times \frac{\sigma A \times \omega}{2\pi} \times \frac{\pi r^2}{2} = \frac{1}{4}\sigma\omega\pi BR^4$

Answer: (d) $\frac{1}{4}\sigma\omega\pi BR^4$

15. The potential energy of magnetic dipole whose dipole moment is $\vec{p}_m = (-0.5\hat{i} + 0.4\hat{j})\text{Am}^2$ kept in uniform magnetic field $\vec{B} = 0.2\hat{i}\text{T}$

- (a) -0.1 J (b) 0.8 J (c) 0.1 J (d) 0.8 J

Hint: $U = -\vec{B} \cdot \vec{p}_m = -(-0.5\hat{i} + 0.4\hat{j}) \cdot 0.2\hat{i}$
 $= 0.1\text{ J}$

Answer: (c) 0.1 J

Creative One Marks Solved

1. At a certain place the horizontal component of earth's magnetic field is $\sqrt{3}$ times vertical component. The angle of dip at that place is

- a) 75° b) 60° c) 45° **d) 30°**

Solution:

$$\tan \delta = \frac{B_V}{B_H} = \frac{1}{\sqrt{3}} \rightarrow \delta = \tan^{-1} \left(\frac{1}{\sqrt{3}} \right) = 30^\circ$$

2. The horizontal component of earth's magnetic field at a place $3.6 \times 10^{-5}\text{ T}$. If the angle of dip at this place is 60° , the vertical components of earth's field at this place is

- a) $1.2 \times 10^{-5}\text{ T}$ b) $2.4 \times 10^{-5}\text{ T}$ c) $4 \times 10^{-5}\text{ T}$ **d) $6.2 \times 10^{-5}\text{ T}$**

Solution:

$$B_V = B_H \tan \delta = 3.6 \times 10^{-5} \times \tan 60^\circ = B_V = 6.2 \times 10^{-5}\text{ T}$$

3. A bar magnet of magnetic moment M is cut into two parts of equal length. The magnetic moment of either part is

- a) M b) $2M$ **c) $\frac{M}{2}$** d) Zero

4. The relative permeability of a paramagnetic material is

- a) greater than unity** b) less than unity
 c) equal to unity d) negative

5. The relative permeability of a diamagnetic material is

- a) greater than unity **b) less than unity**
 c) equal to unity d) negative

6. Soft iron is used in many parts of electrical machines for

- a) low hysteresis loss & low permeability **b) low hysteresis loss & high permeability**

c) high hysteresis loss & low permeability d) high hysteresis loss & high permeability

7. Relative permeability of iron is 5500. Its magnetic susceptibility is

- a) 5501 b) 5500×10^{-7} c) 5500×10^7 **d) 5499**

Solution:

$$\mu_r = 1 + \chi \Rightarrow \chi = \mu_r - 1 = 5500 - 1 = 5499$$

8. When a charged particles enters a uniform magnetic field its kinetic energy

- a) remains constant** b) increases c) decreases d) becomes zero

9. A charged particle (charge q) is moving in a circle of radius R with uniform speed V. The associated magnetic moment is given by

- a) qVR^2 b) $\frac{qVR^2}{2}$ c) qVR **d) $\frac{qVR}{2}$**

Solution:

$$\text{Magnetic moment, } M = IA = \frac{q}{T} (\pi R^2)$$

$$M = \frac{qV}{2\pi R} (\pi R^2) = \frac{qVR}{2}$$

10. A proton enters a magnetic field of flux density 1.5 Wb/m^2 with a speed $2 \times 10^7 \text{ m/s}$ at an angle of 30° with the field. The force on the proton will be

- a) $0.24 \times 10^{-12} \text{ N}$ **b) $2.4 \times 10^{-12} \text{ N}$** c) $24 \times 10^{-12} \text{ N}$ d) $0.024 \times 10^{-12} \text{ N}$

Solution:

$$F = Bqv \sin \theta = 1.5 \times 1.6 \times 10^{-19} \times 2 \times 10^7 \times \sin 30^\circ = 2.4 \times 10^{-12}$$

11. A circular loop has radius R and a current I flows through it. Another circular loop has radius 2R and a current 2I flows through it. Ratio of the magnetic fields at their centres is

- a) $\frac{1}{4}$ **b) 1** c) 2 d) 4

Solution:

$$B_1 = \frac{\mu_0 I}{2R} \text{ and } B_2 = \frac{\mu(2I)}{2(2R)} ; \frac{B_1}{B_2} = 1$$

12. When a magnet of length 2l placed in a uniform magnetic field of B. If its pole strength is q_m then the magnitude of torque is

- a) $p_m B \cos \theta$ **b) $p_m B \sin \theta$** c) $p_m B \tan \theta$ d) $p_m B \cot \theta$

13. The earth's magnetic field at a given point is $0.5 \times 10^{-5} \text{ Wb m}^2$. this field is to be annulled by magnetic induction at the center of circular conducting loop of radius 5 cm. The current required to be flown in the loop is nearly

- a) 0.2 A **b) 0.4 A** c) 4 A d) 40 A

Solution:

$$B = \frac{\mu_0 I}{2r} = I = \frac{2rB}{\mu_0} = \frac{2 \times 0.005 \times 0.5 \times 10^{-5}}{4\pi \times 10^{-7}} = 0.4 \text{ A}$$

14. A circular loop of area 0.01 m^2 and carrying a current of 10 A is placed parallel to a magnetic field of intensity 0.1 T . The torque acting on the loop, in Nm is

- a) 1.1 b) 0.8 c) 0.001 **d) 0.01**

Solution:

$$\tau = BIA = 0.1 \times 10 \times 0.01 = 0.01 \text{ Nm}$$

15. The magnetic moment of a magnet is 5 A m^2 . If the pole strength is 25 A then the length of the magnet is

- a) 25 cm **b) 20 cm** c) 10 cm d) 5 cm

Solution:

$$l = \frac{M}{m} = \frac{5}{25} = 0.2 \text{ m} = \mathbf{20 \text{ cm}}$$

16. Two magnetic poles kept separated by a distance d in vacuum experience a force of 10 N . The force they would experience when kept inside a medium of relative permittivity 2, separated by the same distance is

- a) 10 N b) 5 N c) 40 N **d) 20 N**

Solution:

$$F_m = F \times \epsilon_r = 10 \times 2 = 20$$

17. A long magnetic needle of length $2l$, magnetic moment M and pole strength m is broken into two at the middle. Then, the magnetic moment and pole strength of each piece will be

- a) M, m **b) $\frac{M}{2}, \frac{m}{2}$** c) $\frac{M}{2}, \frac{m}{2}$ d) $M, \frac{m}{2}$

18. A magnet of volume $25 \times 10^{-6} \text{ m}^3$ has a magnetic moment of $4\pi \times 10^{-4} \text{ Am}^2$. Then the intensity of the magnet is

- a) $0.4 \pi \text{ Am}^{-1}$ b) $8 \pi \text{ Am}^{-1}$ c) $4\pi \text{ Am}^{-1}$ **d) $16 \pi \text{ Am}^{-1}$**

Solution:

$$I = \frac{M}{V} = \frac{4\pi \times 10^{-4}}{25 \times 10^{-6}} = 0.16\pi \times 10^{-4+6} = 0.16 \pi \times 10^2 = 16 \pi \text{ Am}^{-1}$$

19. At a particular place the horizontal component of earth's magnetic field is $3 \times 10^{-5} \text{ T}$. If the dip at that place is 60° then the value of magnetic induction is

- a) $3 \times 10^{-5} \text{ T}$ **b) $6 \times 10^{-5} \text{ T}$** c) $12 \times 10^{-5} \text{ T}$ d) $9 \times 10^{-5} \text{ T}$

Solution:

$$B = \frac{B_h}{\cos \theta} = \frac{3 \times 10^{-5}}{\cos 60^\circ} = \frac{3 \times 10^{-5}}{1/2} = 6 \times 10^{-5} \text{ T}$$

20. The length of a conductor is 3m. It is placed perpendicular to a uniform magnetic field of 0.6 T. If a current of 2A flows through the conductor then, the force acting on it will be

- a) **3.6 N** b) 1.8 N c) 0.9 N d) 7.2 N

Solution: $F = BIl = 0.6 \times 2 \times 3 = 3.6 \text{ N}$

21. The direction of force on a current carrying conductor placed in a magnetic field is given by

- a) **Fleming's Left Hand Rule** b) Fleming's Right Hand Rule
c) End Rule d) Right Hand Palm Rule

22. The dimension of magnetic susceptibility is

- a) $M^0 L^0 T^{-1}$ b) **$M^0 L^0 T^0$** c) $M^0 L^{-1} T^{-2}$ d) $M^1 L^{-2} T^{-1}$

23. A current carrying metallic wire of diameter 2mm produces a maximum magnetic field of magnitude of $2 \times 10^{-3} \text{ T}$. What is the value of current passing through the wire?

- a) 40 A b) 20 A c) 5 A d) **10 A**

Solution: $B = \frac{\mu_0 I}{2\pi r}$

$$2 \times 10^{-3} = \frac{4 \times 3.14 \times 10^{-7} \times I}{2 \times 3.14 \times 1 \times 10^{-3}}$$

$$2 \times 10^{-3} = 2I \times 10^{-4} \quad I = \frac{2 \times 10^{-3}}{2 \times 10^{-4}} = 10 \text{ A}$$

24. Two parallel wire carrying current in the same direction will experience

- a) magnetic force b) repulsive force c) electric force d) **attractive force**

25. Cyclotron cannot accelerate

- a) proton b) α – particle c) deuteron d) **electron**

26. A moving coil galvanometer of resistance 20Ω produces full scale deflection of current of 50 A. In order to convert into ammeter of range 20 A the value of resistance to be connected is

- a) 0.005Ω b) **0.05Ω** c) 0.25Ω d) 0.1Ω

Solution:

$$S = G \frac{I_g}{I - I_g} = \frac{20 \times 50 \times 10^{-3}}{20 - 50 \times 10^{-3}} = \frac{1}{20 - 0.05} = \frac{1}{19.95} = 0.05 \Omega$$

27. An alpha particle moves with a velocity of $5 \times 10^3 \text{ m/s}$ at an angle of 30° with respect to a magnetic field of induction 10^{-4} T . Then the force acting on the particle is

- a) $16 \times 10^{-18} \text{ N}$ b) $4 \times 10^{-18} \text{ N}$ c) **$8 \times 10^{-18} \text{ N}$** d) $2 \times 10^{-18} \text{ N}$

$$F_m = qvB \sin \theta = 2 \times 1.6 \times 10^{-19} \times 5 \times 10^3 \times 10^{-4} \times \sin 30^\circ = 8 \times 10^{-18} \text{ N}$$

28. An ideal ammeter and voltmeter has

a) zero and infinite resistance

b) zero and zero resistance

c) infinite and zero resistance

d) infinite and infinite resistance

29. The period of revolution of a charged particle inside a cyclotron does not depend on

a) the magnetic induction

b) the charge of the particle

c) the velocity of the particle

d) the mass of the particle

Solution: Period of revolution, $T = \frac{2\pi m}{qB}$

30. A long solenoid has 40 turns cm. The current necessary to produce a magnetic field of 20 milli tesla inside the solenoid is

a) 7.96 A

b) 15.92 A

c) 3.98 A

d) 1.99 A

Solution:

$$B = \mu_0 n I, n = \frac{40}{10^{-2}} = 4000 \text{ turns/m}$$

$$I = \frac{B}{\mu_0 n} = \frac{20 \times 10^{-3}}{4\pi \times 10^{-7} \times 4000} = \mathbf{3.98 \text{ A}}$$

31. An electron revolves in a circle of radius $0.5 \text{ \AA}$ with a speed of $2 \times 10^6 \text{ m/s}$ in a hydrogen atom. The magnetic field produced at the centre of the orbit due to the electron is

a) 128 T

b) 0.128 T

c) 12.8 T

d) 1.28 T

Solution:

$$n = \frac{\omega}{2\pi} = \frac{v}{2\pi r}$$

$$B = \frac{2\pi q}{r} \left(\frac{v}{2\pi r} \right) \times 10^{-7} = \mathbf{12.8 \text{ T}}$$

32. A proton and an alpha particle, moving with same kinetic energy, enter a uniform magnetic paths will be in the ratio

a) 2:1

b) 1:1

c) 4:1

d) 1: $\sqrt{2}$

Solution: $r = \sqrt{\frac{2mv}{qB^2}}$, r depends upon $\frac{m}{q}$; $r = \sqrt{\frac{m}{q}}$

$$\frac{r_p}{r_\alpha} = \frac{\sqrt{\frac{m_p}{e}}}{\sqrt{\frac{4m_p}{2e}}} = \frac{1}{\sqrt{2}} = \mathbf{1: \sqrt{2}}$$

34. A 2 MeV proton ($m = 1.6 \times 10^{-27} \text{ kg}$) is moving perpendicular to a uniform magnetic field of 2.5 T. The magnetic force on the proton is

a) $8 \times 10^{-11} \text{ N}$

b) $2.5 \times 10^{-12} \text{ N}$

c) $8 \times 10^{-12} \text{ N}$

d) $4 \times 10^{-12} \text{ N}$

Solution:

$$F = Bqv = Bq \times \sqrt{\frac{2E}{m}}$$

$$E = 2 \text{ MeV}$$

$$E = 2.5 \times 1.6 \times 10^{-19}$$

$$F = \sqrt{\frac{2 \times 2 \times 10^6 \times 1.6 \times 10^{-19}}{1.6 \times 10^{-27}}} = 8 \times 10^{-12}$$

35. Magnetic moment associated with the solenoid of 2000 turns and area of cross-section $1.6 \times 10^{-4} \text{ m}^2$ carrying a current of 4.0 A, is suspended through its centre allowing it to turn in a horizontal plane.

- a) **1.28 Am²** b) 1.4 Am² c) 1.6 Am² d) 1.5 Am²

Solution: $M = nIA$

36. When the number of turns (n) in a galvanometer is doubled, current sensitivity

- a) remains constant b) decreases twice
c) **increases twice** d) increases four times

Solution: $\tau = NIBA \sin \theta$

37. What is the reduction factor of a tangent galvanometer 30 cm, if the horizontal intensity of earth's magnetic field of 50 A. turn/m.

- a) **2.5 A** b) 1.5 A c) 1.25 A d) 5A

38. A galvanometer is converted into a voltmeter by connecting a

- a) low resistance in series b) high resistance in parallel
c) **high resistance in series** d) low resistance in parallel

39. The unit of reduction factor of tangent galvanometer is

- a) no unit b) tesla c) ampere d) **ampere / degree**

40. The torque experienced by a rectangular current loop placed perpendicular to a uniform magnetic field is

- a) maximum b) **zero** c) finite minimum d) infinity

41. How will the magnetic field intensity at the centre of a circular wire carrying current change, if the current through the wire is doubled and radius of the coil is halved?

- a) decreased by 4 times b) **increased by 4 times**
c) increased by 8 times d) remains same

42. A galvanometer is converted into a ammeter by connecting a

- a) low resistance in series b) high resistance in parallel
c) high resistance in series d) **low resistance in parallel**

43. A galvanometer has a resistance 30 and gives a full scale deflection for a current of 2mA.

How much resistance in what way must be connected to convert into an ammeter of range 0.3A

- a) 0.4 ohm b) 0.5 ohm c) 0.6 ohm d) **0.2 ohm**

Solution: $S = \frac{GI_g}{I - I_g}$

44. A short bar magnet of magnetic moment $5.25 \times 10^{-2} \text{ J T}^{-1}$ is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with earth's field

- a) 10 cm **b) 5cm** c) 5m d) 10 m

Solution: $B = \frac{\mu_0 M}{4\pi R^3}$

45. In a permanent magnet at room temperature

- (a) magnetic moment of each molecule is zero.
 (b) the individual molecules have non-zero magnetic moment which are all perfectly aligned.
(c) domains are partially aligned.
 (d) domains are all perfectly aligned.

46. Time period of rotation of the electron in the magnetic field when an electron of kinetic energy 25KeV moves perpendicular to the direction of a uniform magnetic field of 0.2 milli tesla

- a) $1.787 \times 10^{-7} \text{ s}$** b) 1.6 s c) 1.8 s d) 1.5 sec

Solution: $T = \frac{2\pi M}{qB}$

49. Force acting on the electron if its velocity is directed towards the wire carries a current of 10A, an electron moving at 10^7 m/s is at distance 2.0 cm from the wire

- a) 1.8 N **b) $1.6 \times 10^{-16} \text{ N}$** c) $1.7 \times 10^{-16} \text{ N}$ d) $1.8 \times 10^{-16} \text{ N}$

Solution: $B = \frac{\mu_0 2I}{4\pi R}$

50. Magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30° with the direction of a uniform magnetic field of 0.15 T

- a) 0.8 Nm^{-1} **b) 0.6 Nm^{-1}** c) 0.5 Nm^{-1} d) 0.9 Nm^{-1}

Solution: $F = BIl \sin \theta$

51. The torque on a rectangular coil placed in a uniform magnetic field is large, when :

- (a) the number of turns is large** (b) the number of turns is less
 (c) the plane of the coil is perpendicular to the field (d) the area of the coil is small

Solution: $\tau = NIBA \sin \theta$

52. Phosphor – bronze wire is used for suspension in a moving coil galvanometer because it has

- a) high conductivity b) high resistivity
 c) large couple per unit twist **d) small couple per unit twist**

1. Define Magnetic field

The magnetic field at a point is defined as a **force experienced by the bar magnet of unit pole strength.**

$$\vec{B} = \frac{\vec{F}}{q_m}$$

2. Define magnetic flux

The number of **magnetic field lines crossing per unit area normally** is called magnetic flux Φ_B .

$$\Phi_B = BA \cos \theta, \text{ Unit: weber (Wb)}$$

3. Define magnetic dipole moment

The magnetic dipole moment is defined as the **product of its pole strength and magnetic length.**

$$\vec{P}_m = q_m \vec{d}, \text{ Unit: Am}^2$$

4. State Coulomb's inverse law

The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

$$\vec{F} \propto \frac{q_{mA} q_{mB}}{r^2} \hat{r}$$

5. What is magnetic susceptibility?

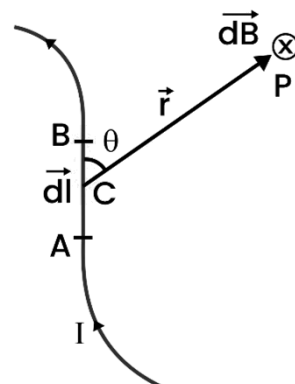
- ✓ It is defined as the ratio of the intensity of magnetisation ($\vec{M}$) induced in the material due to the magnetising field ($\vec{H}$).

$$\chi_m = \frac{\vec{M}}{\vec{H}}$$

6. State Biot-Savart's law

Biot and Savart observed that the magnitude of magnetic field $d\vec{B}$ at a point P at a distance r from the small elemental length taken on a conductor carrying current varies

- (i) directly as the strength of the current I
- (ii) directly as the magnitude of the length element $d\vec{l}$
- (iii) directly as the sine of the angle (say θ) between $d\vec{l}$ and $\hat{r}$



(iv) inversely as the square of the distance between the point P and length element $d\vec{l}$

$$dB \propto \frac{Idl}{r^2} \sin\theta$$

7. What is magnetic permeability?

- ✓ It is measure of ability of the material to allow the passage of magnetic field lines through.
- ✓ It is measure of the capacity of the substance to take magnetisation or the degree of penetration of magnetic field through the substance.

8. State Ampere's circuital law

The line integral of magnetic field over a closed loop is μ_0 times net current enclosed by the loop.

$$\oint_c \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}}$$

9. Compare dia, para & ferro magnetism.

Diamagnetism	Paramagnetism	Ferromagnetism
Magnetic susceptibility is negative	Magnetic susceptibility is positive & small	Magnetic susceptibility is positive and large
Relative permeability is slightly less than unity .	Relative permeability is slightly greater than unity .	Relative permeability is large .
Susceptibility is nearly temperature independent	Susceptibility is inversely proportional to temperature	Susceptibility is inversely proportional to temperature

10. What is meant by hysteresis?

The phenomenon of **lagging** of magnetic induction behind the magnetising field is called hysteresis.

11. Define Magnetic declination and inclination

Magnetic declination (D)

The angle between magnetic meridian at a point and geographical meridian is called the declination or magnetic declination (D).

Dip or magnetic inclination

The angle subtended by the Earth's total magnetic field $\vec{B}$ with the horizontal direction in the magnetic meridian is called dip or magnetic inclination (I) at that point.

12.What is resonance condition in cyclotron?

It is condition in which the frequency f at which the positive ion circulates in the magnetic field is equal to the constant frequency of the electrical oscillator.

$$f_{\text{osc}} = \frac{qB}{2\pi m}$$

13.Define ampere

One ampere is defined as that constant current when it is passed through each of the two infinitely long parallel straight conductors kept side by side parallel at a distance of one meter apart in vacuum causes each conductor to experience a force of 2×10^{-7} newton per meter length of conductor.

14.State Fleming's left hand rule

Stretch forefinger, the middle finger and the thumb of the left hand such that they are in mutually perpendicular directions. If forefinger points the direction of magnetic field, the middle finger points the direction of the electric current, then thumb will point the direction of the force experienced by the conductor.

15.Is an ammeter connected in series or parallel in a circuit? Why?

- ✓ Because in a series connection, the current flowing through all the components of the circuit is the same.
- ✓ Ammeter aims at measuring the current in the circuit, hence it is connected in series so that the same current that is there in the circuit flows through it and gets measured.
- ✓ Ammeter has low resistance because we do not want to change the current that is owing through the circuit.

16.Explain the concept of velocity selector

- ✓ By proper choice of electric and magnetic fields, the particle with particular speed can be selected.
- ✓ Such an arrangement of fields is called a velocity selector.

17. Why is the path of a charged particle not a circle when its velocity is not perpendicular to the magnetic field?

- ✓ Velocity is split up into two components which is parallel to the field remains unchanged and other components which is perpendicular to the field keeps changing due to Lorentz force.
- ✓ It leads to change into path as helical.

18. Give the properties of dia / para / ferromagnetic materials

Properties of diamagnetic materials

- i) Magnetic susceptibility is negative.
- ii) Relative permeability is slightly less than unity.
- iii) Susceptibility is nearly temperature independent.

Properties of paramagnetic materials

- i) Magnetic susceptibility is positive and small.
- ii) Relative permeability is greater than unity.
- iii) Susceptibility is inversely proportional to temperature.

Properties of ferromagnetic materials

- i) Magnetic susceptibility is positive and large.
- ii) Relative permeability is large.
- iii) Susceptibility is inversely proportional to temperature.

19. What happens to the domains in a ferromagnetic material in the presence of external magnetic field?

- ✓ Domains having magnetic moments parallel to the field grow in size
- ✓ Other domains (not parallel to field) are rotated so that they are aligned with the field.

20. How is a galvanometer converted into (i) an ammeter (ii) voltmeter

(i) Ammeter

A galvanometer is converted into an ammeter by connecting **a low resistance in parallel** with the galvanometer.

(ii) Voltmeter

A galvanometer is converted into a voltmeter by connecting **high resistance R_h in series** with galvanometer.

Short Answers - Book Inside

1. Obtain the relation between total magnetic field, magnetising field and intensity of magnetisation

$\vec{B} = \vec{B}_m + \vec{B}_o$ Where $\vec{B}_m$ – Magnetic field produced in vacuum $\vec{B}_o$ – induced magnetic field

$$\vec{B}_m = \mu_o \vec{I} \qquad \vec{B}_o = \mu_o \vec{H}$$

$$\vec{B} = \mu_o (\vec{H} + \vec{I})$$

2. What are elements of the Earth's magnetic field.

- (a) magnetic declination (D)
- (b) magnetic dip or inclination (I)
- (c) the horizontal component of the Earth's magnetic field (B_H)

3. How does Aurora borealis occurs?

It occurs due to the result of interaction between gaseous particle in the earth's atmosphere with highly charged particle released from the sun atmosphere through solar wind

4. Define Geometric & magnetic length

The length of the bar magnet is called geometrical length and the length between two magnetic poles in a bar magnet is called magnetic length. Magnetic length is always slightly smaller than geometrical length.

5. Define magnetic flux density

The magnetic flux density can also be defined as the number of magnetic field lines crossing unit area kept normal to the direction of line of force.

6. Define Tangent law

When a magnetic needle or magnet is freely suspended in two mutually perpendicular uniform magnetic fields, it will come to rest in the direction of the resultant of the two fields

$$B = B_h \tan \theta$$

7. Define Magnetising field ($\vec{H}$)

The magnetic field which is used to magnetize a sample or specimen is called the magnetising field.

Quantity: Vector **Unit:** $A\ m^{-1}$.

8. Define Meissner effect.

The expulsion of magnetic flux from a superconductor during its transition to the superconducting state is known as Meissner effect.

9. Define Current sensitivity

It is defined as the deflection produced per unit current flowing through it.

$$I_s = \frac{\theta}{I}$$

10. How will you increase the current sensitivity of a galvanometer

$$I_s = \frac{NAB}{K}$$

It is increased by changing

- 1) the number of turns N 2) the magnetic induction B
- 3) the area of the coil A 4) decreasing couple per unit twist

11. Define voltage sensitivity

It is defined as the deflection produced per unit voltage applied across it.

$$V_s = \frac{\theta}{V}$$

12. Define Curie's law

Susceptibility is inversely proportional to temperature

$$\chi_m \propto \frac{1}{T}$$

13. Define Curie-Weiss law.

At a particular temperature, ferromagnetic material becomes paramagnetic. This temperature is known as Curie temperature T_C .

$$\chi_m = \frac{C}{T - T_C}$$

14. Define coercivity.

The magnitude of the reverse magnetising field for which the residual magnetism of the material vanishes is called its coercivity.

15. Define retentivity

It is defined as the ability of the materials to retain the magnetism in them even magnetising field vanishes.

16.State Right hand thumb rule

If we hold the current carrying conductor in our right hand such that the thumb points in the direction of current flow, then the fingers encircling the wire points in the direction of the magnetic field lines produced.

17. State Maxwell's right hand cork screw rule

If we rotate a right hand screw using a screw driver then the direction of current is same as direction in which screw advances and the direction of rotation of screw gives direction of magnetic field

19. What are Limitations of cyclotron

- 1) the speed of the ion is limited
- 2) electron cannot be accelerated
- 3) uncharged particles cannot be accelerated

20.Define one tesla

The strength of the magnetic field is one tesla if unit charge moving in it with unit velocity experiences unit force

21.Define Figure of merit of a galvanometer

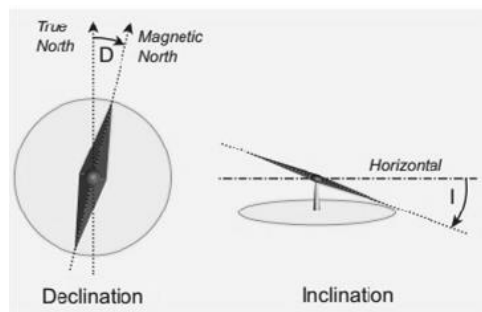
It is defined as the current which produces a deflection of one scale division in the galvanometer.

Long Answers - Book Back

1.Discuss Earth's magnetic field in detail

The three quantities required to specify the magnetic field on the earth on its surface , which are often called as elements of Earth's magnetic field .They are

- (a) magnetic declination (D)
- (b) magnetic dip or inclination (I)
- (c) the horizontal component of the Earth's magnetic field (B_H)



(a) The angle between magnetic meridian at a point and geographical meridian is called the declination or **magnetic declination (D)**.

(b) The angle subtended by the Earth's total magnetic field with the horizontal direction in the magnetic meridian is called **dip or magnetic inclination (I) at that point**.

(c) The component of Earth's magnetic field along the horizontal direction in the magnetic meridian is called **horizontal component of Earth's magnetic field (B_H)**

B_E – net Earth's magnetic field at a point P on the surface of the Earth.

B_E can be resolved into two perpendicular components.

Horizontal component

$$B_H = B_E \cos I \text{ ----(1)}$$

Vertical component $B_V = B_E \sin I \text{ ----(2)}$

Dividing (2) by (1) $\rightarrow \tan I = \frac{B_V}{B_H}$

(i) At magnetic equator

angle of dip, $I = 0^\circ$.

$$B_H = B_E, B_V = 0$$

Horizontal component is maximum at equator and **vertical component is zero** at equator.

(ii) At magnetic poles

angle of dip, $I = 90^\circ$.

Hence, $B_H = 0, B_V = B_E$

Vertical component is maximum at poles and **horizontal component is zero** at poles

2. Deduce the relation for the magnetic induction at a point due to an infinitely long straight conductor carrying current using Biot-Savart law

✓ Consider infinitely long straight conductor XY and I be the steady current through the conductor.

✓ Let us consider a small line element dl (segment AB).

The magnetic field at a point P due to current element $I dl$ is $d\vec{B} =$

$$\frac{\mu_0}{4\pi} \frac{Idl \sin \theta}{r^2} \hat{n} \text{ ----(1)}$$

In triangle ABC: $\sin \theta = \frac{AC}{AB}$

$$AC = AB \sin \theta$$

$$AC = dl \sin \theta \text{ ----(2) Where } AB = dl$$

In triangle APC: $\sin d\phi = \frac{AC}{AP}$

$$AC = r \sin \phi = r d\phi \text{ ----(3) where } AP = r$$

Equating (2) and (3)

$$dl \sin \theta = r d\phi$$

sub $dl \sin \theta = r d\phi$ in (1)

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I}{r^2} (r d\phi) \hat{n} = \frac{\mu_0}{4\pi} \frac{I d\phi}{r} \hat{n} \text{ ---- (4)}$$

In triangle

OPA: $\cos \phi =$

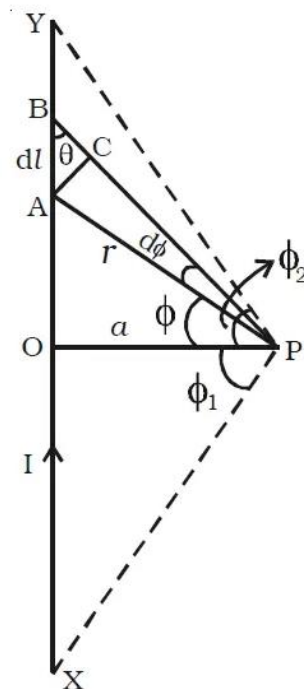
$$\frac{OP}{AP} = \frac{a}{r}$$

$$r = \frac{a}{\cos \phi}$$

$$\text{Sub } r = \frac{a}{\cos \phi}$$

in (4)

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I}{a/\cos \phi} d\phi \hat{n}$$



$$\Rightarrow d\vec{B} = \frac{\mu_0 I}{4\pi a} \cos\theta d\theta \hat{n}$$

Total magnetic field at a point due to the conductor YY'

$$\vec{B} = \int_{-\theta_1}^{\theta_2} d\vec{B}$$

$$= \int_{-\theta_1}^{\theta_2} \frac{\mu_0 I}{4\pi a} \cos\theta d\theta \hat{n} = \frac{\mu_0 I}{4\pi a} [\sin\theta]_{-\theta_1}^{\theta_2} \hat{n}$$

$$\vec{B} = \frac{\mu_0 I}{4\pi a} (\sin\theta_1 + \sin\theta_2) \hat{n}$$

For long infinitely conductor

$$\theta_1 = \theta_2 = 90^\circ$$

$$\vec{B} = \frac{\mu_0 I}{4\pi a} \times 2\hat{n} \Rightarrow \frac{\mu_0 I}{2\pi a} \hat{n}$$

3. Obtain a relation for the magnetic induction at a point along the axis of a circular coil carrying current using Biot-Savart law

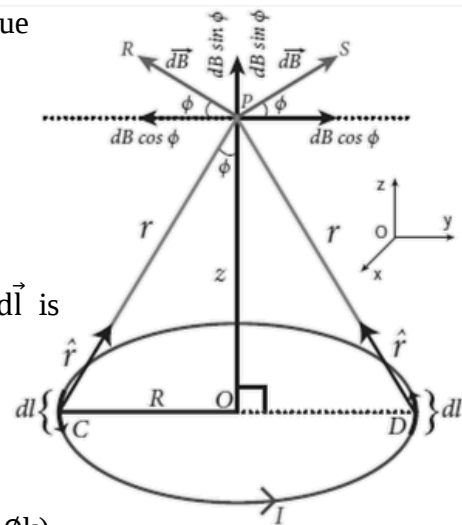
- ✓ Consider a current carrying circular loop of radius R.
- ✓ I be the current flowing through the wire in the direction.
- ✓ The magnetic field at a point P on the axis of the circular coil at a distance z from its center of the coil O.
- ✓ Consider two diametrically opposite line elements of the coil each of length $d\vec{l}$ at C & D.

According to Biot-Savart's law, the magnetic field at P due to the current element $I d\vec{l}$ is

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I d\vec{l} \times \hat{r}}{r^2} \dots\dots\dots(1)$$

Magnitude of $d\vec{B}$ is $dB = \frac{\mu_0}{4\pi} \cdot \frac{Idl}{r^2}$

- ✓ The magnetic field due to each current element $I d\vec{l}$ is resolved into two components; $dB \sin\theta$ along z - direction and $dB \cos\theta$ along y - direction.
- ✓ Horizontal components of each current element cancels out while the vertical components ($dB \sin\theta$) alone contribute to total magnetic field at the point P.



$$\vec{B} = \int d\vec{B} = \int dB \sin\theta \hat{k} = \frac{\mu_0 I}{4\pi} \int \frac{dl}{r^2} \sin\theta \hat{k}$$

From Triangle OCP

$$\sin\theta = \frac{R}{\sqrt{R^2 + z^2}}$$

$$r = \sqrt{R^2 + z^2}$$

Sub these values in above equation

$$\vec{B} = \frac{\mu_0 I}{4\pi} \frac{R}{(R^2 + z^2)^{3/2}} \hat{k} \int dl$$

$$\vec{B} = \frac{\mu_0 I}{4\pi} \frac{R}{(R^2 + z^2)^{3/2}} \hat{k} (2\pi R)$$

$$\vec{B} = \frac{\mu_0 I}{2} \frac{R^2}{(R^2 + Z^2)^{3/2}} \hat{k}$$

If it contains N turns

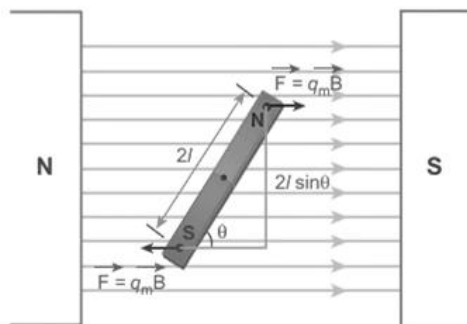
$$\vec{B} = \frac{\mu_0 NI}{2} \frac{R^2}{(R^2 + Z^2)^{3/2}} \hat{k}$$

The magnetic field at the centre of the coil is

$$\vec{B} = \frac{\mu_0 NI}{2R} \hat{k} \text{ since } z = 0$$

4. Compute the torque experienced by a magnetic needle in a uniform magnetic field

- ✓ Consider a magnet of length $2l$ of pole strength q_m kept in a uniform magnetic field.
- ✓ Each pole experiences a force of magnitude $q_m B$ but acts in opposite direction.
- ✓ Therefore, the net force exerted on the magnet is zero, so that there is no translatory motion. These two forces constitute a couple (about midpoint of bar magnet) which will rotate and try to align in the direction of the magnetic field



The force experienced by north pole

$$\vec{F}_N = q_m \vec{B} \text{ ----- (1)}$$

The force experienced by South pole

$$\vec{F}_S = -q_m \vec{B} \text{ ----- (2)}$$

Adding (1) & (2)

Net force on the dipole as

$$\vec{F} = \vec{F}_N + \vec{F}_S = 0$$

Torque experienced by north and south pole about point O is

$$\begin{aligned} \vec{\tau} &= \vec{ON} \times \vec{F}_N + \vec{OS} \times \vec{F}_S \\ &= \vec{ON} \times q_m \vec{B} + \vec{OS} \times (-q_m \vec{B}) \end{aligned}$$

By using right hand cork screw rule, we conclude that the total torque is pointing into the paper.

Since the magnitudes: $|\vec{ON}| = |\vec{OS}| = l$

$$|\vec{B} q_m| = |-\vec{B} q_m|$$

Magnitude of total torque about point O

$$\begin{aligned} \tau &= l \times q_m B \sin \theta + l \times q_m B \sin \theta \\ &= 2l \times q_m B \sin \theta \\ &= P_m B \sin \theta \text{ (Since } P_m = q_m \times 2l \text{)} \end{aligned}$$

In vector notation: $\vec{\tau} = \vec{P}_m \times \vec{B}$

5. Calculate the magnetic induction at a point on the axial line of bar magnet

- ✓ Consider a bar magnet NS. N - North Pole and S -south pole of the bar magnet, each of pole strength q_m and separated by a distance of $2l$.
- ✓ The magnetic field at a point C (lies along the axis of the magnet) at a distance from the geometrical center O of the bar magnet can be computed by keeping unit north pole ($q_{mC} = 1 \text{ A m}$) at C.

The magnetic field at C due to north pole is $\vec{B}_N = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{i}$ ----- (1)

The magnetic field at C due to south pole is

$$\vec{B}_S = -\frac{\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{i} \text{----- (2)}$$

$$\vec{B} = \vec{B}_N + \vec{B}_S$$

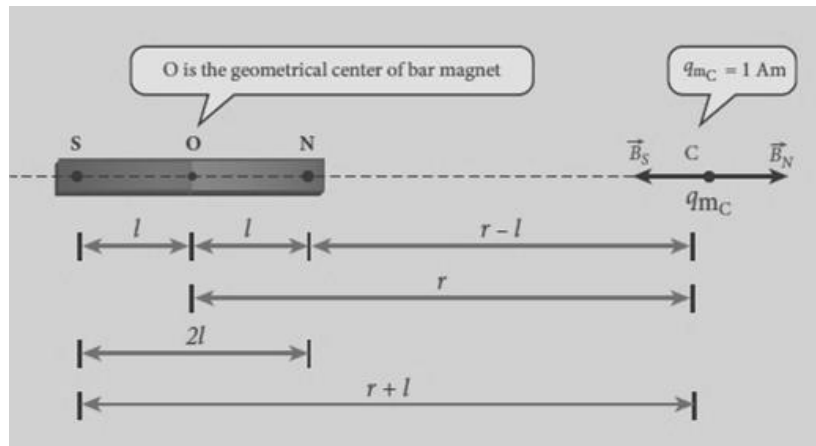
$$\begin{aligned} \vec{B} &= \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{i} - \frac{\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{i} \\ &= \frac{\mu_0}{4\pi} q_m \left(\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2} \right) \hat{i} \\ &= \frac{\mu_0}{4\pi} 2r \left(\frac{q_m 2l}{(r^2 - l^2)^2} \right) \hat{i} \end{aligned}$$

$$p_m = q_m \times 2l$$

$$\vec{B}_{\text{axial}} = \frac{\mu_0}{4\pi} \frac{2r p_m}{(r^2 - l^2)^2} \hat{i}$$

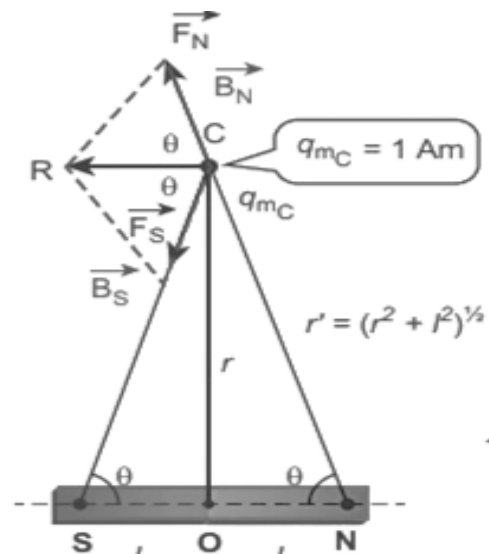
$$r \gg l \quad (r^2 - l^2)^2 \approx r^4$$

$$\begin{aligned} \vec{B}_{\text{axial}} &= \frac{\mu_0}{4\pi} \frac{2 p_m}{r^3} \hat{i} \\ &= \frac{\mu_0}{4\pi} \frac{2}{r^3} \vec{p}_m \end{aligned}$$



6. Obtain the magnetic induction at a point on the equatorial line of bar magnet

- ✓ Consider a bar magnet NS.
- ✓ N - north pole & S - south pole of the bar magnet, each with pole strength q_m and separated by a distance of $2l$.
- ✓ The magnetic field at a point C (lies along the equatorial line) at a distance r from the geometrical center O of the bar magnet can be computed by keeping unit north pole ($q_{mC} = 1 \text{ A m}$) at C.



- ✓ The force experienced by the unit north pole at C due to pole strength N-S can be computed using Coulomb's law of magnetism

The force of repulsion between North Pole of the bar magnet and unit north pole at point C (in free space) is

$$\vec{B}_N = -B_N \cos \theta \hat{i} + B_N \sin \theta \hat{j}$$

$$B_N = \frac{\mu_0}{4\pi} \frac{q_m}{r'^2} \text{ ---- (1)}$$

$$\vec{B}_S = -B_S \cos \theta \hat{i} - B_S \sin \theta \hat{j}$$

$$B_S = \frac{\mu_0}{4\pi} \frac{q_m}{r'^2} \text{ ---- (2)}$$

$$\vec{B} = \vec{B}_S + \vec{B}_N$$

$$\vec{B} = -(B_N + B_S) \cos \theta \hat{i}$$

$$B_N = B_S$$

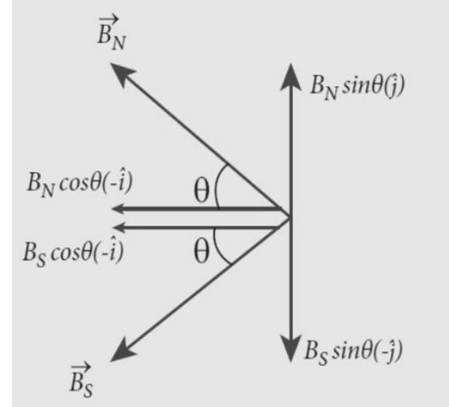
$$\vec{B} = -2 \frac{\mu_0}{4\pi} \frac{q_m}{r'^2} \cos \theta \hat{i} \text{ ---- (3)}$$

$$r'^2 = r^2 + l^2$$

In right angle triangle

$$\cos \theta = \frac{1}{(r^2 + l^2)^{\frac{1}{2}}}$$

$$\text{Sub } \cos \theta = \frac{1}{(r^2 + l^2)^{\frac{1}{2}}} \text{ in (3) equation}$$



$$\vec{B} =$$

$$-2 \frac{\mu_0}{4\pi} \frac{q_m}{r^2 + l^2} \times \frac{1}{(r^2 + l^2)^{\frac{1}{2}}} \hat{i}$$

$$= -\frac{\mu_0}{4\pi} \frac{2l \times q_m}{(r^2 + l^2)^{\frac{3}{2}}} \hat{i}$$

$$= -\frac{\mu_0}{4\pi} \frac{p_m}{(r^2 + l^2)^{\frac{3}{2}}} \hat{i} \text{ (since } p_m = q_m \times 2l \text{)}$$

$$r \gg l \quad (r^2 + l^2)^{\frac{3}{2}} = (r^2)^{\frac{3}{2}} = r^3$$

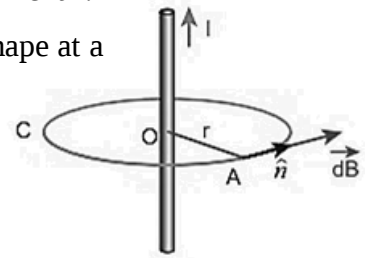
$$\vec{B}_{\text{equatorial}} = -\frac{\mu_0}{4\pi} \frac{p_m}{r^3} \hat{i}$$

$$\text{Since } p_m \hat{i} = \vec{p}_m$$

$$\text{Therefore } \vec{B}_{\text{equatorial}} = -\frac{\mu_0}{4\pi} \frac{\vec{p}_m}{r^3}$$

7. Find the magnetic induction due to a straight conductor using ampere's circuital law

- ✓ Consider a straight conductor of infinite length carrying current I.
- ✓ Constructing an Amperian loop in the form of a circular shape at a distance r from the centre of the conductor
- ✓ $\oint_C \vec{B} \cdot d\vec{l} = \mu_0 I$



Hence, the angle between magnetic field vector and line element is zero

$$\oint_C \vec{B} \cdot d\vec{l} = \mu_0 I$$

Magnitude of the magnetic field is uniform over the Amperian loop.

$$B \oint_C dl = \mu_0 I$$

$$B \int_0^{2\pi r} dl = \mu_0 I$$

$$B \cdot 2\pi r = \mu_0 I$$

$$B = \frac{\mu_0}{2\pi r} I$$

$$\text{In vector form: } \vec{B} = \frac{\mu_0}{2\pi r} I \hat{n}$$

8. Discuss the working of cyclotron in detail.

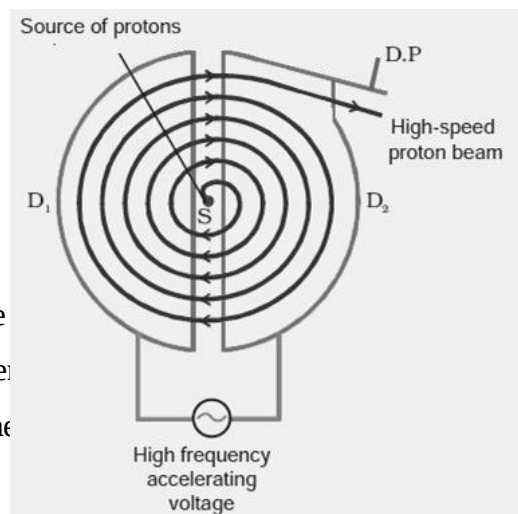
Cyclotron is a device used to **accelerate the charged particles** to gain large kinetic energy.

Principle

When a charged particle moves normal to the magnetic field, it experiences magnetic Lorentz force.

Working

- 1) Ion ejected from source S is positively charged.
- 2) As soon as ion is ejected, it is accelerated towards a Dee (say, Dee – 1) which has negative potential at that time.
- 3) Since the magnetic field is normal to the plane of the Dees, the ion undergoes circular path. After semi-circular path in Dee-1, the ion reaches the gap between Dees.
- 4) At this time, the polarities of the Dees are reversed so that the ion is now accelerated towards Dee-2 with a greater velocity.
- 5) For this circular motion, the centripetal force of the charged particle q is provided by Lorentz force. $r = \frac{mv}{qB}$ (1) $r \propto v$
- 6) From the equation (1), the increase in velocity increases the radius of circular path.
- 7) This process continues and hence the particle undergoes spiral path of increasing radius.
- 8) Once it reaches near the edge, it is taken out with the help of deflector plate and allowed to hit the target T.
- 9) Resonance condition has to occur for operation of cyclotron in which frequency f at which the positive ion circulates in the magnetic field must be equal to the constant frequency of the electrical oscillator f_{osc} where $f_{osc} = \frac{qB}{2\pi m}$.
- 10) Time period of oscillation $T = \frac{2\pi m}{qB}$ & kinetic energy of the charged particle



Limitations of cyclotron

- (a) the speed of the ion is limited (b) electron cannot be accelerated

(c) uncharged particles cannot be accelerated

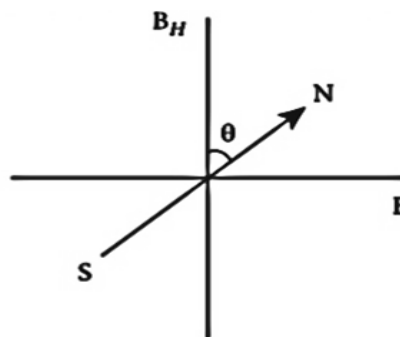
9. What is tangent law? Give in detail

Statement

When a magnetic needle or magnet is freely suspended in two mutually perpendicular uniform magnetic fields, it will come to rest in the direction of the resultant of the two fields

Explanation

- ✓ When no current is passed through the coil, the small magnetic needle lies along horizontal component of Earth's magnetic field.
- ✓ When the circuit is switched ON, the electric current will pass through the circular coil and produce magnetic field.
- ✓ Now there are two fields which are acting mutually perpendicular to each other. They are: the magnetic field (B) due to the electric current in the coil acting normal to the plane of the coil. (2) horizontal component of Earth's magnetic field (B_H).
- ✓ Because of these crossed fields, the pivoted magnetic needle deflects through an angle θ . From tangent law $B = B_H \tan \theta$ ----- (1)
- ✓ When an electric current is passed through a circular coil of radius R having N turns, the magnitude of magnetic field at the center is



$$B = \mu_0 \frac{NI}{2R} \text{ ----- (2)}$$

Comparing (1) & (2)

$$\mu_0 \frac{NI}{2R} = B_H \tan \theta$$

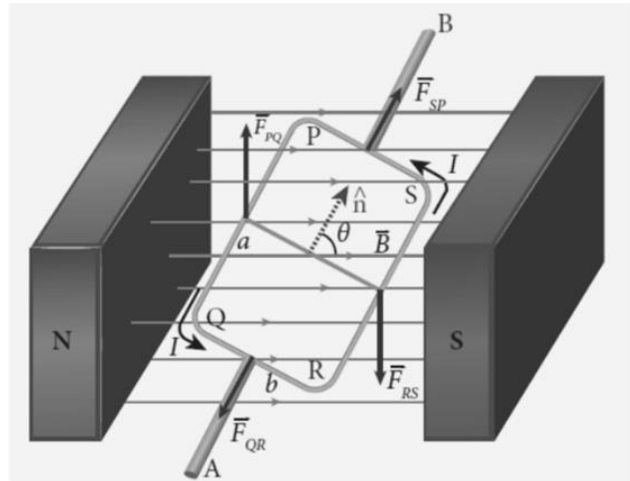
$$B_H = \mu_0 \frac{NI}{2R} \frac{1}{\tan \theta} \text{ in tesla}$$

$$I = K \theta$$

$$K = \frac{2RB_H}{N\mu_0} \text{ ----- Reduction factor}$$

10. Derive the expression for the torque on a current carrying coil in a magnetic field.

- ✓ Consider a rectangular loop PQRS carrying current I is placed in a uniform magnetic field B .
- ✓ a and b be the length and breadth of rectangular loop
- ✓ Unit vector $\hat{n}$ normal to the plane of the loop makes an angle θ with the magnetic field.



Force acting on current-carrying arm PQ

$$F_{PQ} = BIL \sin \theta = BIa \sin \left(\frac{\pi}{2} \right) = BIa \quad [\text{Here } L = a, \theta = \frac{\pi}{2}]$$

Force acting on current-carrying arm RS $F_{RS} = BIL \sin \theta = BIa \sin \left(\frac{\pi}{2} \right) = BIa$

Force acting upward on arm PQ and downwards on arm RS

Force acting on current-carrying arm QR

$$F_{QR} = BIL \sin \theta = BIb \sin \left(\frac{\pi}{2} - \theta \right) = BI \cos \theta \quad [\text{Here } L = b, \theta = \frac{\pi}{2} - \theta, \sin \left(\frac{\pi}{2} - \theta \right) = \cos \theta]$$

Force acting on current-carrying arm SP

$$F_{QR} = BIL \sin \theta = BIb \sin \left(\frac{\pi}{2} + \theta \right) = BI \cos \theta \quad [\text{Here } L = b, \theta = \frac{\pi}{2} + \theta, \sin \left(\frac{\pi}{2} + \theta \right) = \cos \theta]$$

Force acting on arms QR & SP are equal, opposite and collinear, they cancel each other.

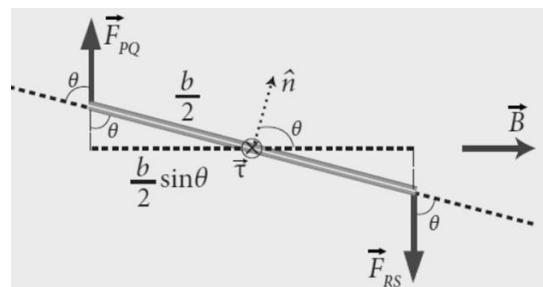
Force acting on current-carrying arm PQ and RS constitute a couple which exerts a torque on the loop.

Torque acting on the arm PQ about AB

$$\tau_{PQ} = F_{PQ} \times d = BIa \times \frac{b}{2} \sin \theta$$

Torque acting on the arm RS about AB

$$\tau_{RS} = F_{RS} \times d = BIa \times \frac{b}{2} \sin \theta$$



$$\text{Total torque} = \tau_{PQ} + \tau_{RS} = BIa \times \frac{b}{2} \sin \theta + BIa \times \frac{b}{2} \sin \theta$$

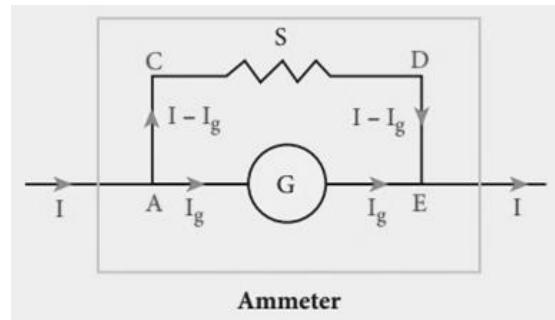
$$= \frac{2BIab \sin \theta}{2} = BIab \sin \theta = BIA \sin \theta$$

If there are N turns in the rectangular loop, then the torque $= NBI A \sin \theta$

11. Discuss the conversion of galvanometer into an ammeter and also a voltmeter

Galvanometer to an Ammeter

- ✓ A galvanometer is converted into an ammeter by connecting a low resistance in parallel with the galvanometer. This low resistance is called shunt resistance S .
- ✓ The scale is now calibrated in ampere and the range of ammeter depends on the values of the shunt resistance.
- ✓ Let I be the current passing through the circuit.
- ✓ When current I reaches the junction A , it divides into two components.
- ✓ Let I_g be the current passing through the galvanometer of resistance R_g through a path AGE and the remaining current $(I - I_g)$ passes along the path $ACDE$ through shunt resistance S .
- ✓ Value of shunt resistance is so adjusted that current I_g produces full scale deflection in the galvanometer.



$$V_{\text{galvanometer}} = V_{\text{shunt}}$$

$$I_g R_g = (I - I_g) S$$

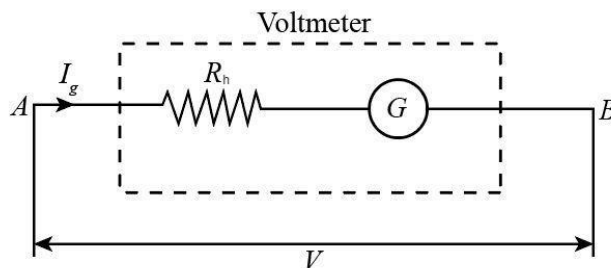
$$S = \frac{I_g}{(I - I_g)} R_g$$

$$I_g = \frac{S}{S + R_g} I$$

- ✓ Deflection in the galvanometer is proportional to the current passing through it.
- ✓ $\theta = \frac{1}{G} I_g \quad \theta \propto I_g \quad \theta \propto I$
- ✓ An ideal ammeter is one which has zero resistance.

Galvanometer to a voltmeter

- ✓ A galvanometer is converted into a voltmeter by **connecting high resistance R_h in series** with galvanometer.
- ✓ The scale is now calibrated in volt and the range of voltmeter depends on the values of the resistance connected in series.
- ✓ R_g - resistance of galvanometer and I_g be the current with which the galvanometer produces full scale deflection.
- ✓ Since the galvanometer is connected in series with high



resistance, the current in the electrical circuit is same as the current passing through the galvanometer.

$$I = I_g$$

The voltmeter resistance is

$$R_V = R_g + R_h$$

$$I_g = \frac{V}{R_g + R_h}$$

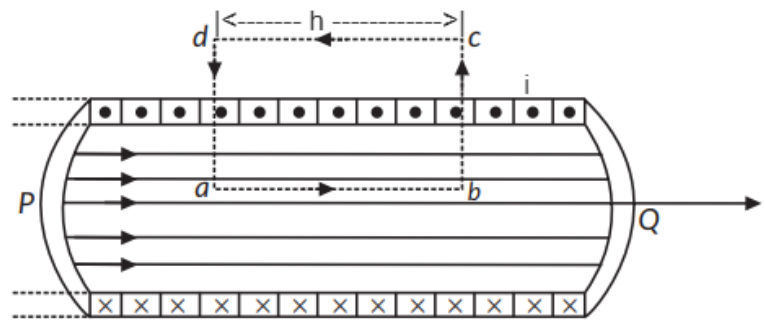
$$R_h = \frac{V}{I_g} - R_g$$

$$I_g \propto V$$

- ✓ Deflection in the galvanometer is proportional to potential difference.
- ✓ An ideal voltmeter is one which has infinite resistance.

12. Calculate the magnetic field inside and outside of the long solenoid using Ampere's circuital law

- ✓ Consider a solenoid of length L having N turns.
- ✓ The diameter of the solenoid is assumed to be much smaller when compared to its length and the coil is wound very closely.



From Ampere's circuital law to rectangular loop abcd:

$$\oint_c \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}}$$

$$\oint_c \vec{B} \cdot d\vec{l} = \int_a^b \vec{B} \cdot d\vec{l} + \int_b^c \vec{B} \cdot d\vec{l} + \int_c^d \vec{B} \cdot d\vec{l} + \int_d^a \vec{B} \cdot d\vec{l}$$

For elemental length along bc & da magnetic field perpendicular to them

$$\int_b^c \vec{B} \cdot d\vec{l} = \int_b^c |\vec{B}| |d\vec{l}| \cos 90^\circ = 0$$

$$\text{Similarly, } \int_d^a \vec{B} \cdot d\vec{l} = 0$$

Magnetic field outside the solenoid is zero

$$\int_c^d \vec{B} \cdot d\vec{l} = 0$$

For the path along ab, integral is

$$\int_a^b \vec{B} \cdot d\vec{l} = B \int_a^b dl \cos 0^\circ = B \int_a^b dl = BL$$

NI – current passing through the solenoid of N turns

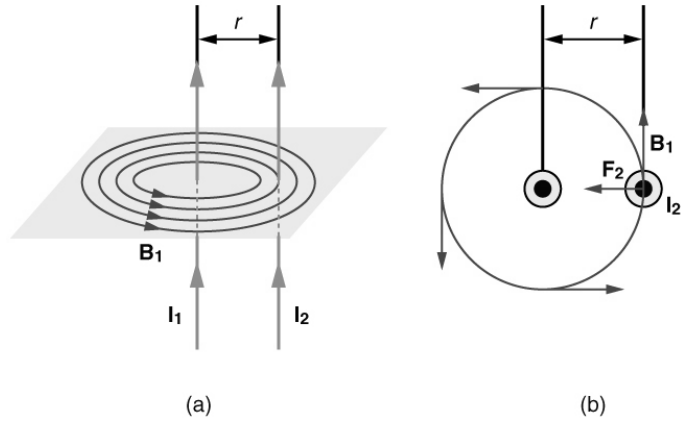
$$BL = \mu_0 NI = \mu_0 \frac{NI}{L} = \mu_0 nI$$

$$\mathbf{B} = \mu_0 n\mathbf{I}$$

For a fixed current I , the magnetic field inside the solenoid is also a constant.

13. Derive an expression for Force acting between two long parallel current carrying conductors

- ✓ Consider Two long straight parallel current carrying conductors separated by a distance r are kept in air
- ✓ I_1 and I_2 be the electric currents passing through the conductors A and B in same



direction (i.e. along z - direction)

The net magnetic field at a distance r due to current I_1 in conductor A is

$$\vec{B}_1 = \frac{\mu_0 I_1}{2\pi r} (-\hat{i}) = -\frac{\mu_0 I_1}{2\pi r} \hat{i} \quad \text{----- (1)}$$

Lorentz force on the element dl of conductor B at which the magnetic field $\vec{B}_1$ is present is

$$\begin{aligned} d\vec{F} &= (I_2 d\vec{l} \times \vec{B}_1) = -I_2 dl \frac{\mu_0 I_1}{2\pi r} (\hat{k} \times \hat{i}) \\ &= -\frac{\mu_0 I_1 I_2 dl}{2\pi r} \hat{j} \end{aligned}$$

The force per unit length of the conductor B due to the wire conductor A is

$$\frac{\vec{F}}{l} = -\frac{\mu_0 I_1 I_2}{2\pi r} \hat{j} \quad \text{----- (2)}$$

In the same manner, magnitude of net magnetic induction due to current I_2 (in conductor A) at a distance r in the elemental length dl of conductor A is calculated

$$\vec{B}_2 = \frac{\mu_0 I_2}{2\pi r} \hat{i}$$

Lorentz force on the element dl of conductor A at which the magnetic field $\vec{B}_2$ is present is

$$\begin{aligned} d\vec{F} &= (I_1 d\vec{l} \times \vec{B}_2) = I_1 dl \frac{\mu_0 I_2}{2\pi r} (\hat{k} \times \hat{i}) \\ &= \frac{\mu_0 I_1 I_2 dl}{2\pi r} \hat{j} \end{aligned}$$

The force per unit length of the conductor B due to the wire conductor A is

$$\frac{\vec{F}}{l} = \frac{\mu_0 I_1 I_2}{2\pi r} \hat{j} \quad \text{----- (3)}$$

- ✓ Force experienced by two parallel current carrying conductors is **attractive** if the direction of electric current passing through them is **same**
- ✓ Force experienced by two parallel current carrying conductors is **repulsive** if they carry current in the **opposite directions**

14. Give an account of magnetic Lorentz force.

- ✓ When an electric charge q is moving with velocity $\vec{v}$ in the magnetic field $\vec{B}$, it experiences a force, called magnetic force.
- ✓ If charge moving in the electric and magnetic field, it experiences a force, called magnetic Lorentz force.
- ✓ After careful experiments, Lorentz deduced the force experienced by a moving charge in the magnetic field

$$\vec{F}_m = q(\vec{v} \times \vec{B})$$

$$\text{In magnitude } F_m = qvB \sin \theta$$

Force is directly proportional to

(i) Magnetic field $\vec{B}$

(ii) velocity $\vec{v}$

(iii) directly proportional to sine of the angle between the velocity and magnetic field

(iv) charge q

- ✓ Direction of force is always perpendicular to $\vec{v}$ & $\vec{B}$
- ✓ Direction of force on negative charge is opposite to direction of force on positive charge
- ✓ If velocity of the charge is along magnetic field then force is zero.

15. Compare the properties of soft and hard ferro magnet

Soft ferro magnetic materials	Hard ferro magnetic materials
Area of loop is small	Area of loop is large
Retentivity is low	Retentivity is large
Coercivity is low	Coercivity is large
Hysteresis loss is less	Hysteresis loss is More
Susceptibility and magnetic permeability is high	Susceptibility and magnetic permeability is low

16. Derive an expression for Force on a current carrying conductor placed in a magnetic field

- ✓ When a current carrying conductor is placed in a magnetic field, the force experienced by the wire is equal to the sum of Lorentz forces on the individual charge carriers in the wire.
- ✓ Consider a small segment of wire of length dl , with cross-sectional area A and current I

$$I = nAev_d \text{ ---- (1)}$$

If the wire is kept in a magnetic field $\vec{B}$, then average force experienced by the electron in the wire is

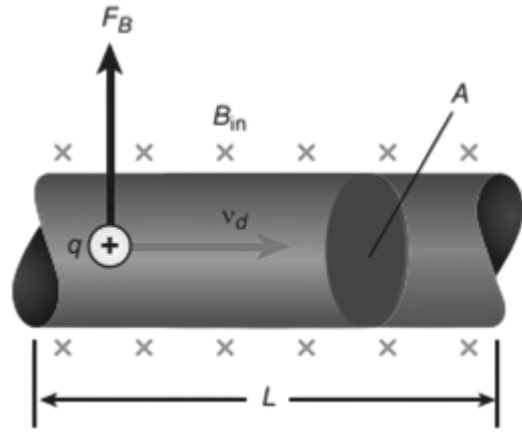
$$\vec{F} = -e (\vec{v}_d \times \vec{B}) \text{ ---- (2)}$$

$$n = \frac{N}{V} \text{ ---- (3)}$$

N - is the number of free electrons

$$V = A \cdot dl$$

$$N = n \times V = nAdl$$



$$q = Ne = enAdl \text{ ---- (4)}$$

$$d\vec{F} = -e nAdl (\vec{v}_d \times \vec{B})$$

$$I \cdot d\vec{l} = -enA\vec{v}_d dl$$

$$d\vec{F} = I d\vec{l} \times \vec{B}$$

The force in a straight current carrying conducting wire of length l placed in a uniform magnetic field is

$$\vec{F} = I \vec{l} \times \vec{B}$$

In magnitude $F = BIl \sin\theta$

17. Explain the principle and working of a moving coil galvanometer.

It is used to detect the flow of current in an electrical circuit.

Principle

When a current carrying loop is placed in a uniform magnetic field, it experiences a torque.

Working

- ✓ Consider a single turn of the rectangular coil PQRS whose length is l and breadth b . $PQ = RS = l$ and $QR = SP = b$.
- ✓ Let I be the electric current flowing through the rectangular coil PQRS.
- ✓ The horse-shoe magnet has hemi-spherical magnetic poles which produces a radial magnetic field.
- ✓ Due to this radial field, the sides QR and SP are always parallel to the magnetic field B and experience no force.
- ✓ The sides PQ and RS are always perpendicular to the magnetic field and experience equal forces in opposite directions.

✓ Due to this, torque is produced.

For single turn, the deflecting torque is $\tau = bF = bBI = (lb) BI = ABI$

$$A = lb$$

For coil with N turns, we get

$$\tau = NABI$$

Due to this deflecting torque, the coil gets twisted and restoring torque (also known as restoring couple) is developed. Hence the moment of the restoring torque is proportional to the amount of twist θ .

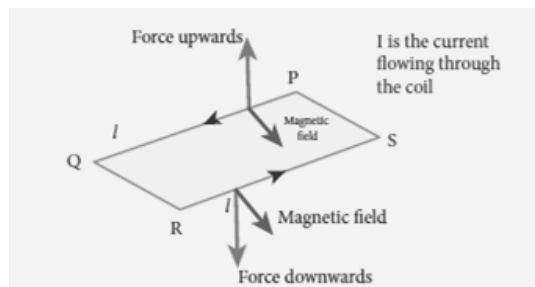
$\tau = K\theta$ where K is the restoring couple per unit twist.

At equilibrium, the deflecting couple must be equal to the restoring couple. Therefore we get,

$$NABI = K\theta$$

$$I = \frac{K}{NAB} \theta$$

$$I = G\theta \text{ Where } G = \frac{K}{NAB}$$



Long Answers - Book Inside

1. Write about Properties of magnet

1. A freely suspended bar magnet will always point along the north-south direction.
2. A magnet attracts another magnet or magnetic substances towards itself. The attractive force is maximum near the end of the bar magnet.
3. When a magnet is broken into pieces, each piece behaves like a magnet with poles at its ends.
4. Two poles of a magnet have pole strength equal to one another.
5. The length of the bar magnet is called geometrical length and the length between two magnetic poles in a bar magnet is called magnetic length. Magnetic length is always slightly smaller than geometrical length. The ratio of magnetic length and geometrical length is $\frac{5}{6}$.

2. Write about properties of Magnetic field lines

1. Magnetic field lines are continuous closed curves.
2. The direction of magnetic field lines is from North pole to South pole outside the magnet and South pole to North pole inside the magnet.
3. The direction of magnetic field at any point on the curve is known by drawing tangent to the magnetic line of force at that point.

4. Magnetic field lines never intersect each other.

5. The degree of closeness of the field lines determines the relative strength of the magnetic field. The magnetic field is strong where magnetic field lines crowd and weak where magnetic field lines thin out.

3. Explain about Applications of hysteresis loop

i) Permanent magnets:

The materials with high retentivity, high coercivity and high permeability are suitable for making permanent magnets.

Examples: Steel and Alnico

ii) Electromagnets:

The materials with high initial permeability, low retentivity, low coercivity and thin hysteresis loop with smaller area are preferred to make electromagnets.

iii) Core of the transformer:

The materials with high initial permeability, large magnetic induction and thin hysteresis loop with smaller area are needed to design transformer cores.

Examples: Soft iron

4.Explain Magnetic dipole moment of revolving electron

Suppose an electron undergoes circular motion around the nucleus, The circulating electron in a loop is like current in a circular loop (since flow of charge is current).

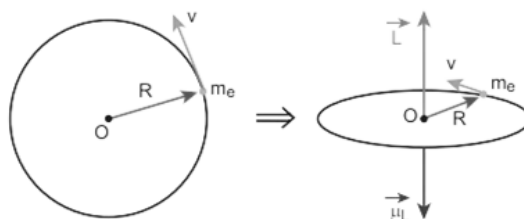
The magnetic dipole moment due to current carrying circular loop is

$$\vec{\mu}_L = I \vec{A} \text{ ----- (1)}$$

In magnitude $\mu_L = IA \text{ ----- (2)}$

If T is the time period of an electron, the current due to circular motion of the electron is

$$I = \frac{-e}{T} \text{ ----- (3)}$$



$$\text{Velocity of electron } v = \frac{2\pi R}{T} \text{ ----- (4)}$$

Sub T value in (3)

$$I = \frac{-ev}{2\pi R} \text{ ----- (5)}$$

Sub (5) in (2) where $A = \pi R^2$

$$\mu_L = \frac{-ev}{2\pi R} \times \pi R^2 = \frac{-evR}{2} \text{ ----- (6)}$$

Multiplying and divide (6) by m

$$\mu_L = \frac{-emvR}{2m} \text{ ----- (7)}$$

Where Magnitude of angular momentum of electron about O is $L = mvR$ ----- (8)

By (8) , eq (7) became

$$\frac{\mu_L}{L} = \frac{-e}{2m} \text{ ----- (9)}$$

$$\begin{aligned} \text{In magnitude } \frac{\mu_L}{L} &= 0.0878 \times 10^{12} \\ &= 8.78 \times 10^{10} \text{ C Kg}^{-1} \end{aligned}$$

$$L = n \frac{h}{2\pi}$$

$$\frac{\mu_L}{L} = \frac{e}{2m} \text{ ----- (10)}$$

Sub L value in (10)

$$\mu_L = n \frac{h}{2\pi} \frac{e}{2m}$$

Sub value of h, e , m in above equation

$$\mu_L = n \times 9.27 \times 10^{-24} \text{ Am}^2 = \mu_B \text{ (Bohr magneton)}$$

5.What is toroid? Obtain an expression for magnetic field at a point.

(a) In open space interior to the toroid (b) In open space exterior to the toroid

(c) Inside the toroid

- ✓ A solenoid is bent in such a way its ends are joined together to form a closed ring shape, is called a toroid
- ✓ The magnetic field has constant magnitude inside the toroid whereas in the interior region (say, at point P) and exterior region (say, at point Q), the magnetic field is zero.

(a) Open space interior to the toroid

- ✓ Let us calculate the magnetic field B_P at point P.
- ✓ construct an Amperian loop 1 of radius r_1 around the point P
- ✓ Since, the loop1 encloses no current,
- ✓ $I_{\text{enclosed}} = 0$ Therefore For loop 1 $\oint \vec{B}_P \cdot d\vec{l} = 0$
- ✓ This is possible only if the magnetic field at point P vanishes i.e. $\vec{B}_P = 0$

(b) Open space exterior to the toroid

- ✓ Let us calculate the magnetic field B_Q at point Q. We construct an Amperian loop 3 of radius r_3 around the point Q
- ✓ Since, in each turn of the toroid loop, current coming out of the plane of paper is cancelled by the current going into the plane of paper. Thus, $I_{\text{enclosed}} = 0$

✓ For loop 3 $\oint \vec{B}_Q \cdot d\vec{l} = 0$

✓ $\vec{B}_Q = 0$

(c) Inside the toroid

Let us calculate the magnetic field B_S at point S by constructing an Amperian loop 2 of radius r_2 around the point S

The length of the loop is $L_2 = 2\pi r_2$

For loop 2 $\oint \vec{B}_S \cdot d\vec{l} = \mu_0 I_{\text{enclosed}} \text{ ----- (1)}$

$I_{\text{enclosed}} = NI \text{ ----- (2)}$

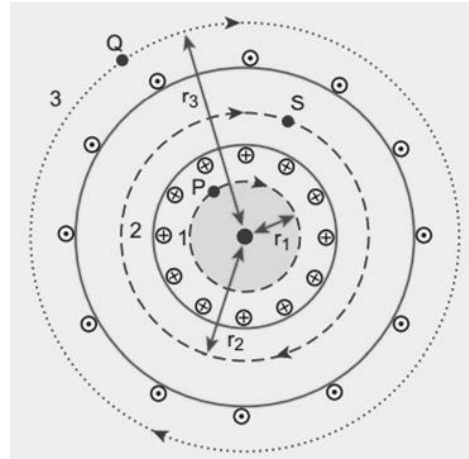
For loop 2 $\oint \vec{B}_S \cdot d\vec{l} = \oint B_S \cdot dl \cos \theta$
 $= B_S 2\pi r_2 \text{ ----- (3)}$

Sub (3) & (2) in (1)

$$B_S = \mu_0 \frac{NI}{2\pi r_2}$$

$$\frac{N}{2\pi r_2} = n$$

$$B_S = \mu_0 nI$$



Numerical Problems Solved

1. A bar magnet having a magnetic moment $\vec{M}$ is cut into four pieces i.e., first cut in two pieces along the axis of the magnet and each piece is further cut into two pieces. Compute the magnetic moment of each piece.

Solution:

A bar magnet of magnetic moment $\vec{M}$.

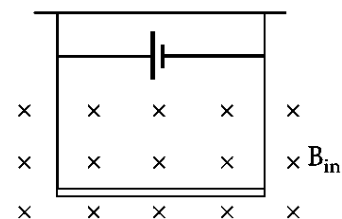
When a bar magnet first cut in two pieces along the axis, their magnetic moment is $\frac{\vec{M}}{2}$.

Each piece is further cut into two pieces.

Their magnetic moment of each piece is $\frac{\vec{M}}{4}$.

Magnetic moment of each piece: $\therefore \vec{p}_m' = \frac{1}{4} \vec{p}_m$

2. A conductor of linear mass density 0.2 g m^{-1} suspended by two flexible wire as shown in figure. Suppose the tension in the supporting wires is zero when it is kept inside the magnetic field of 1 T whose direction is into the page. Compute the current inside the conductor and also the direction of the current. Assume $g = 10 \text{ m s}^{-2}$



Given: Magnetic field, $B = 1 \text{ T}$,

Solution

Downward force, $F = mg$

Linear mass density

$$\frac{m}{l} = 0.2 \times 10^{-3} \text{ kg m}^{-1}$$

$m = \text{Linear mass density} \times l$

$$m = 0.2 \times 10^{-3} \times l \quad (\because g = 10 \text{ ms}^{-2})$$

$$F = mg = 0.2 \times 10^{-3} \times l \times 10$$

$$F = 2 \times 10^{-3} l \rightarrow (1)$$

$$F = BIL = 1 \times I \times l \rightarrow (2)$$

This is upward magnetic force acting on the wire.

From (1) and (2)

$$I \times l = 2 \times 10^{-3} l;$$

$$I = 2 \text{ mA}$$

3. A circular coil with cross-sectional area 0.1 cm^2 is kept in a uniform magnetic field of strength 0.2 T . If the current passing in the coil is 3 A and plane of the loop is perpendicular to the direction of magnetic field. Calculate

(a) total torque on the coil

(b) total force on the coil

(c) average force on each electron in the coil due to the magnetic field of the free electron density for the material of the wire is 10^{28} m^{-3} .

Given: $A = 0.1 \text{ cm}^2 = 0.1 \times (10^{-2} \text{ m})^2$, $n = 10^{28} \text{ m}^{-3}$, $B = 0.2 \text{ T}$, $I = 3 \text{ A}$

$\therefore$ Angle between the magnetic field and normal to the coil, $\theta = 0^\circ$

Solution:

(a) Total torque on the coil,

$$\tau = ABI \sin \theta$$

$$= 0.1 \times 10^{-4} \times 0.2 \times 3 \times \sin 0^\circ$$

$$\tau = 0$$

(b) Total force on the coil,

$$F = BIL \sin \theta$$

$$F = 0.2 \times 3 \times l \times \sin 0^\circ$$

$$F = 0$$

(c) Average force:

$$F = qV_d B,$$

$$\text{Drift velocity, } V_d = \frac{I}{neA}$$

$$F = e \times \frac{I}{neA} \times B \quad (q = e)$$

$$F = \frac{IB}{nA} = \frac{3 \times 0.2}{10^{28} \times 0.1 \times 10^{-4}}$$

$$F = 6 \times 10^{-24} \text{ N,}$$

$$F = 0.6 \times 10^{-23} \text{ N}$$

4. A bar magnet is placed in a uniform magnetic field whose strength is 0.8 T. Suppose the bar magnet orient at an angle 30° with the external field experiences a torque of 0.2 N m. Calculate:

(i) the magnetic moment of the magnet

(ii) the work done by an applied force in moving it from most stable configuration to the most unstable configuration and also compute the work done by the applied magnetic field in this case.

Given: $B = 0.8 \text{ T}$, $\theta = 30^\circ$, $\tau = 0.2 \text{ Nm}$

Solution:

$$(i) \tau = P_m B \sin \theta$$

$$P_m = \frac{\tau}{B \sin \theta} = \frac{0.2}{0.8 \times \sin 30^\circ} = \frac{1}{4 \times \frac{1}{2}}$$

$$P_m = 0.5 \text{ Am}^2$$

(ii) In stable configuration work done by an applied force,

$$w = -2P_m B$$

$$w = 2 \times 0.5 \times 0.8 = 0.8 \text{ J}$$

(iii) In unstable configuration work done by an applied force,

Work done by applied magnetic field, $W = u_f - u_i$

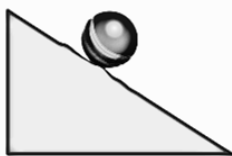
$$= -P_m B - (P_m B)$$

$$W = -2P_m B$$

$$W = -2 \times 0.5 \times 0.8$$

$$W = -0.8 \text{ J}$$

5. A non - conducting sphere has a mass of 100 g and radius 20 cm. A flat compact coil of wire with turns 5 is wrapped tightly around it with each turns concentric with the sphere. This sphere is placed on an inclined plane such that plane of coil is parallel to the inclined plane. A uniform magnetic field of 0.5 T exists in the region in vertically upward direction. Compute the current I required to rest the sphere in equilibrium.



Given: Mass of the sphere $m = 100 \text{ g}$, $g = 100 \times 10^{-3} \text{ kg}$, Radius, $R = 20 \text{ cm} = 20 \times 10^{-2} \text{ m}$, Number of turns, $n = 5$, Uniform magnetic field, $B = 0.5 \text{ T}$, $I = ?$

Solution:

At equilibrium,

$$f_s R - P_m B \sin \theta = 0$$

$$\begin{aligned} P_m &= IA, \\ \text{for } n' \text{ turns} \\ P_m &= N \times IA \end{aligned}$$

$$f_s R = P_m B \sin \theta, \theta = 90^\circ$$

$$mgR = NIAB$$

$$I = \frac{mgR}{NBA} = \frac{mgR}{NB \times \pi R^2} = \frac{mg}{NB \cdot \pi R}$$

$$I = \frac{100 \times 10^{-3} \times 10}{5 \times \frac{1}{2} \times \pi \times 20 \times 10^{-2}}$$

$$I = \frac{20}{\pi} \times 10^{-1}$$

$$I = \frac{2}{\pi} \text{ A}$$

6. Calculate the magnetic field at the center of a square loop which carries a current of 1.5 A, length of each loop is 50 cm.

Given:

$I = 1.5 \text{ A}$, length of each loop, $l = 50 \text{ cm} = 0.5 \text{ m}$

Magnetic field at the centre of current carrying square loop, $B' = ?$

Solution

According to Biot – savart law magnetic field due to a current carrying straight wire,

$$\begin{aligned} B' &= \frac{\mu_0 I}{4\pi a} [\sin \phi_1 + \sin \phi_2] \\ &= \frac{4\pi \times 10^{-7} \times 1.5}{4\pi \times 0.25} [\sin 45^\circ + \sin 45^\circ] \\ &= 6 \times 10^{-7} \times \left[\frac{1}{\sqrt{2}} + \frac{1}{\sqrt{2}} \right] \end{aligned}$$

$$= 6 \times 10^{-7} \times \frac{2}{\sqrt{2}} = 6 \times 10^{-7} \times \frac{\sqrt{2} \times \sqrt{2}}{\sqrt{2}}$$

$$B' = 6 \times 10^{-7} \times 1.414$$

$$B' = 8.484 \times 10^{-7} \text{ T}$$

$\therefore$ For four sides,

$$B' = 4 \times 8.484 \times 10^{-7}$$

$$= 33.9 \times 10^{-7}$$

$$B' = 3.4 \times 10^{-6} \text{ T}$$

UNIT 4 – ELECTROMAGNETIC INDUCTION & ALTERNATING CURRENT

Important Questions

Two Marks

Two Marks	
Book Back	Book inside

1.State Faraday’s law of electro magnetic induction. 2. State Lenz’s law 3.State Fleming’s right hand rule 4. What is meant by electromagnetic induction? 5.How is Eddy current is produced 6.Mention the ways of producing induced emf 7. How will you define Q-factor? 8. Give any one definition of power factor 9.What are step up and step down transformer? 10. List out the advantages of stationary armature – rotating field system of AC generator 11. What do you meant by wattless current?	1. What is meant by wattful current? 2. Give the Advantages of AC over DC 3. Give the Disadvantages of AC 4. A capacitor allow AC but blocks DC why?
Three Marks	
1. Show that Lenz’s law is in accordance with the law of conservation of energy 2. Obtain an expression for Motional emf from Lorentz force 3. Assuming that the length of the solenoid is large when compared to its diameter, find the equation for its inductance 4. An inductor of inductance L carries an electric current I .How much energy is stored while establishing the current in 5. How will you induce an emf by changing the area enclosed by the coil? 6.Mention the various energy losses in a transformer 7. Find out phase relationship between voltage and current in a pure inductor circuit	1. Find out the phase relationship between voltage and current in pure capacitive circuit.
Five marks	
1. Show that the mutual inductance between a pair of coil is same ($M_{12} = M_{21}$) 2.Show mathematically that the rotation of a coil in a magnetic over one rotation induces an alternating emf of one cycle 3. Explain the construction and working of transformer 4. Derive an expression for phase angle between the applied voltage & current in a series RLC circuit 5. Obtain an expression for average power of AC over a cycle.Discuss its special cases. 6. Explain the working of single – phase AC generator with necessary diagram	

Important Formulae

1. Magnetic flux $\phi_B = \vec{B} \cdot \vec{A} = BA \cos \theta$

2. Rate of change of magnetic flux $= \frac{d\phi_B}{dt}$

3. Magnitude of induced emf $\varepsilon = -\frac{Nd\phi_B}{dt}$

4. Coefficient of self-induction

$$\varepsilon = -\frac{d}{dt} (Li)$$

5. Self inductance of a long solenoid

$$L = \mu n^2 Al \left(\because n = \frac{N}{l} \right),$$

$$L = \frac{\mu_0 N^2 A}{l}; L = \mu_0 \mu_r n^2 Al$$

6. Energy stored in inductor

$$U_B = \frac{1}{2} Li^2$$

7. Coefficient of mutual induction;

$$M_{12} = -\frac{\varepsilon_1}{\frac{di_2}{dt}} \text{ (or) } M_{21} = -\frac{\varepsilon_2}{\frac{di_1}{dt}}$$

8. Mutual induction of two long solenoids

$$M = \mu n_1 n_2 Al = \mu_0 \mu_r n_1 n_2 Al$$

9. Induced emf by changing

(i) Area $\varepsilon = -Blv$

(ii) Orientation of coil $\varepsilon = NBA\omega \sin \omega t$

10. Energy density, $\mu_B = \frac{U_B}{Al} = \frac{\frac{1}{2} Li^2}{Al}$

11. Power dissipated $P = i^2 R = \frac{B^2 l^2 v^2}{R}$

12. Quality factor (Q – factor) $= \frac{1}{R} \sqrt{\frac{L}{C}}$

13. Transformer ratio: $\frac{N_s}{N_p} = \frac{I_p}{I_s} = \frac{V_s}{V_p} = k$

23. **AC through capacitor:** Current leads the voltage by $\frac{\pi}{2}$;

$$v = V_m \sin \omega t; i = I_m \sin(\omega t + \frac{\pi}{2}); i_m = \frac{V_m}{X_C} \text{ Capacitive reactance } X_C = \frac{1}{\omega C} = \frac{1}{2\pi \nu C}$$

24. LCR circuit

(a) Impedance $Z = \sqrt{R^2 + (X_L - X_C)^2}$ (b) Phase angle $\Phi = \tan^{-1} \frac{(X_L - X_C)}{R}$

(c) Resonant frequency $\nu_0 = \frac{1}{2\pi \sqrt{LC}}$ (d) Instantaneous current $= I_m \sin(\omega t \pm \Phi)$

14. Step up transformer:

$$k > 1, N_s > N_p, V_s > V_p, I_s < I_p$$

15. Step down transformer:

$$k < 1, N_s < N_p, V_s < V_p, I_s > I_p$$

16. Efficiency of transformer

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100\%$$

17. $I_{av} = 0.6371 I_m$

18. Power in A.C circuit

$$P_{av} = V_{rms} I_{rms} \cos \Phi$$

19. Effective current

$$I_{eff} = I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m$$

20. Effective voltage

$$E_{eff} = E_{rms} = \frac{E_m}{\sqrt{2}} = 0.707 E_m$$

21. **AC through a resistor:** E & I are in phase with each other.

$$\varepsilon = E_m \sin \omega t \quad i = I_m \sin \omega t; \quad I_m = \frac{V_m}{R}$$

22. **AC through an inductor:** emf leads the current by 90° or $\frac{\pi}{2}$

$$e = E_0 \sin(\omega t + \frac{\pi}{2}); i = I_m \sin(\omega t - \frac{\pi}{2})$$

$$\text{where } I_m = \frac{V_m}{X_L}$$

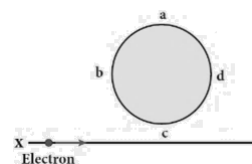
$$\text{Inductive reactance } X_L = 2\pi \nu L = \omega L$$

Units

Parameter	SI unit	Parameter	SI unit
Induced emf	volt(V)	Capacitance	farad(F)
Magnetic flux	weber(W)	Resistance	ohm(Ω)
Magnetic field	Weber or $\left(\frac{\text{tesla}}{\text{m}^2}\right)$	Impedance	ohm(Ω)
Inductance	henry(H)	Reactance	ohm(Ω)

Text Book One Marks Solved

1. An electron moves on a straight line path XY as shown in the figure. The coil abcd is adjacent to the path of the electron. What will be the direction of current, if any, induced in the coil?

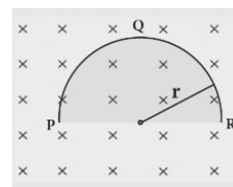


- (a) The current will reverse its direction as the electron goes past the coil
- (b) No current will be induced
- (c) abcd
- (d) adcb

Hint: When the electron moves from X to Y, the flux linked with the coil abcd (which is into the page) will first increase and then decrease as the electron passes by. So the induced current in the coil will be first anticlockwise and will reverse its direction (i.e. will become clockwise) as the electron goes past the coil.

Answer: (a) The current will reverse its direction as the electron goes past the coil

2. A thin semi-circular conducting ring (PQR) of radius r is falling with its plane vertical in a horizontal magnetic field B , as shown in the figure. The potential difference developed across the ring when its speed v , is



- (a) Zero
- (b) $\frac{Bv\pi r^2}{2}$ and P is at higher potential
- (c) πBv and R is at higher potential
- (d) $2rBv$ and R is at higher potential

Hint: Motional emf induced in the semi circular ring PQR is equivalent to the motional emf induced in the imaginary conductor PR. $\varepsilon_{PQR} = \varepsilon_{PR} = Bvl = Bv(2r)$

Therefore, potential difference developed across the ring is $2rBv$ with R is at higher potential.

Answer: (d) $2rBv$ and R is at higher potential

3. The flux linked with a coil at any instant t is given by $\phi_B = 10t^2 - 50t + 250$. The induced emf at $t = 3s$ is

- (a) -190 V (b) -10 V (c) 10 V (d) 190 V

Hint:

$$\varepsilon = -\frac{d}{dt}(d\phi_B) = \frac{d}{dt}(10t^2 - 50t + 250) = -(20t - 50)$$

Sub $t = 3$ in above equation

Answer: (b) -10 V

4. When the current changes from $+2\text{ A}$ to -2 A in 0.05 s , an emf of 8 V is induced in a coil.

The co-efficient of self-induction of the coil is

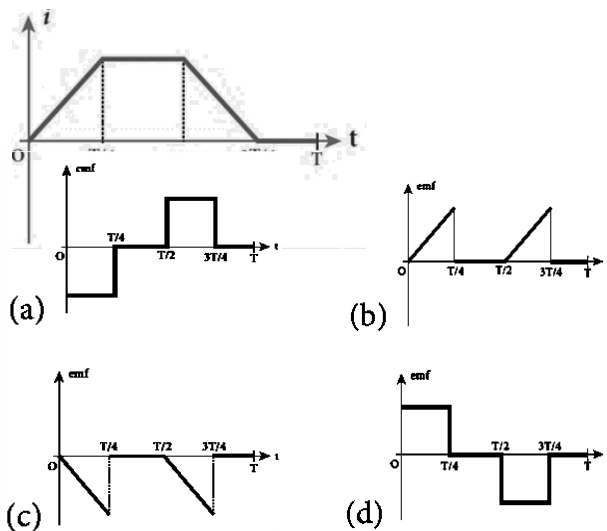
- (a) 0.2 H (b) 0.4 H (c) 0.8 H (d) 0.1 H

Hint: $\varepsilon = -L \frac{di}{dt}$; $L = -\frac{\varepsilon}{\frac{di}{dt}}$

$$\frac{di}{dt} = \frac{-4}{0.05} \quad L = -\frac{8}{\frac{-4}{0.05}} = 0.1\text{ H}$$

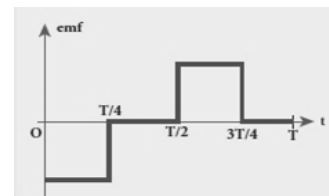
Answer: (d) 0.1 H

5. The current i flowing in a coil varies with time as shown in the figure. The variation of induced emf with time would be



Hint: In (a) ; 0 to $T/4$ - Flux changes (negative) , $T/4$ to $T/2$ - no changes in flux
 $T/2$ to $3T/4$ flux changes (positive)

Answer: (a)



6. A circular coil with a cross-sectional area of 4 cm^2 has 10 turns. It is placed at the centre of a long solenoid that has 15 turns/cm and a cross-sectional area of 10 cm^2 . The axis of the coil coincides with the axis of the solenoid. What is their mutual inductance?

- (a) $7.54 \mu\text{H}$ (b) $8.54 \mu\text{H}$ (c) $9.54 \mu\text{H}$ (d) $10.54 \mu\text{H}$

Hint: $M = \mu_0 N_1 N_2 A_2 = 4\pi \times 10^{-7} \times 15 \times 10^{-2} \times 10 \times 4 \times 10^{-4}$

Answer: (a) $7.54 \mu\text{H}$

7. In a transformer, the number of turns in the primary and the secondary are 410 and 1230 respectively. If the current in primary is 6A, then that in the secondary coil is

- (a) 2 A (b) 18 A (c) 12 A (d) 1 A

Hint: $\frac{N_s}{N_p} = \frac{I_p}{I_s} \rightarrow I_s = \frac{N_p I_p}{N_s} = \frac{410 \times 6}{1230} = 2\text{A}$

Answer: (a) 2 A

8. A step-down transformer reduces the supply voltage from 220 V to 11 V and increase the current from 6 A to 100 A. Then its efficiency is

- (a) 1.2 (b) 0.83 (c) 0.12 (d) 0.9

Hint: $\eta = \frac{\text{output power}}{\text{input power}} = \frac{11 \times 100}{220 \times 6} = 0.83$

Answer: (b) 0.83

9. In an electrical circuit, R, L, C and AC voltage source are all connected in series. When L is removed from the circuit, the phase difference between the voltage and current in the circuit is $\pi/3$. Instead, if C is removed from the circuit, the phase difference is again $\pi/3$. The power factor of the circuit is

- (a) $\frac{1}{2}$ (b) $\frac{1}{\sqrt{2}}$ (c) 1 (d) $\frac{\sqrt{3}}{2}$

Hint: $X_L = X_C$. Power factor $\cos \phi = \frac{R}{Z} = 1$ where $R = Z$

Answer: (c) 1

10. In a series RL circuit, the resistance and inductive reactance are the same. Then the phase difference between the voltage and current in the circuit is

- (a) $\pi/4$ (b) $\pi/2$ (c) $\pi/6$ (d) zero

Hint: $X_L = R \Rightarrow \tan \phi = \frac{X_L}{R} = 1$

Answer: (a) $\pi/4$

11. In a series resonant RLC circuit, the voltage across 100Ω resistor is 40 V. The resonant frequency ω is 250 rad/s. If the value of C is $4 \mu\text{F}$, then the voltage across L is

- (a) 600 V (b) 4000 V (c) 400V (d) 1 V

Hint: $X_L = X_C = \frac{1}{\omega C} = \frac{1}{250 \times 4 \times 10^{-6}} = 10^3 \Omega$. $I = \frac{V}{R} = \frac{40}{100} = 0.4 \text{ A}$

$V = IX_L = 400 \text{ V}$

Answer: (c) 400V

12. An inductor 20 mH, a capacitor 50 μF and a resistor 40 Ω are connected in series across a source of emf $v = 10 \sin 340 t$. The power loss in AC circuit is

- (a) 0.76 W (b) 0.89 W (c) 0.46 W (d) 0.67 W

Hint: $V_{\text{rms}} = \frac{V_0}{\sqrt{2}} = 0.707 \times V_0 = 0.707 \times 10 = 7.07$

$X_L = L\omega = 6.8, X_C = \frac{1}{\omega C} = 58.8$

$Z = \sqrt{R^2 + (X_L - X_C)^2} = \sqrt{40^2 + (58.8 - 6.8)^2} = 65.6$

$P_{\text{av}} = \left(\frac{V_{\text{rms}}}{Z} \right) \frac{R}{Z} = 0.46$

Answer: (c) 0.46 W

13. The instantaneous values of alternating current and voltage in a circuit are

$i = \frac{1}{\sqrt{2}} \sin(100\pi t) \text{ A}$ & $v = \frac{1}{\sqrt{2}} \sin(100\pi t + \frac{\pi}{3}) \text{ V}$. The average power in watts consumed in the circuit is

- (a) $\frac{1}{4}$ (b) $\frac{\sqrt{3}}{4}$ (c) $\frac{1}{2}$ (d) $\frac{1}{8}$

Hint : $P_{\text{av}} = \frac{V_m I_m}{2} \cos \Phi = \frac{1}{2} \times \frac{1}{\sqrt{2}} \times \frac{1}{\sqrt{2}} \times \cos \frac{\pi}{3} = \frac{1}{8}$

Answer: (d) 1/8

14. In an oscillating LC circuit, the maximum charge on the capacitor is Q. The charge on the capacitor when the energy is stored equally between the electric and magnetic fields is

- (a) $\frac{Q}{2}$ (b) $\frac{Q}{\sqrt{3}}$ (c) $\frac{Q}{\sqrt{2}}$ (d) Q

Hint: $U = \frac{Q^2}{2C}$

Energy stored equally therefore charge on the capacitor $= \frac{1}{2} \times \frac{Q^2}{2C} = \frac{Q}{\sqrt{2}}$

Answer: (c) $\frac{Q}{\sqrt{2}}$

15. $\frac{20}{\pi^2}$ inductor is connected to a capacitor of capacitance C. The value of C in order to impart maximum power at 50 Hz is

- (a) 50 μF (b) 0.5 μF (c) 500 μF (d) 5 μF

Hint : $X_L = X_C \rightarrow L\omega = \frac{1}{\omega C} \rightarrow C = \frac{1}{\omega^2 L} = 5 \times 10^{-6} \text{ F}$

Answer: (d) 5 μf

Creative One Marks Solved

1. For a d.c. circuit, the value of capacitive reactance (X_c) is

- a) zero **b) infinity** c) $\frac{\pi}{2}$ d) π

2. A power of 11 KW is in transmitted through 220 V. the current through line wire is

- a) 5A b) 0.5 A **c) 50 A** d) 500 A

Solution: $I = \frac{P}{V} = \frac{11000}{220} = 50 \text{ A}$

3. The reactance offered by 300 mH conductor to an AC supply of frequency 50 Hz is

- a) 942 Ω **b) 94.2 Ω** c) 1046 Ω d) 104.6 Ω

Solution: $X_L = L\omega = 300 \times 10^{-3} \times 2 \times 3.14 \times 50 = 94.2 \Omega$

4. The frequency at which 2 H inductor with reactance of $20 \pi \Omega$ is an AC circuit with inductor only is

- a) 15 Hz **b) 5 Hz** c) 50 Hz d) 100 Hz

Solution:

$$X_L = 20 \pi \rightarrow L \times 2\pi\gamma = 20\pi$$

$$2 \times 2 \times 3.14\gamma = 20 \times 3.14$$

$$4\gamma = 20 \rightarrow \gamma = 5 \text{ Hz}$$

5. Which of the following devices does not allow direct current (D.C.) to pass through?

- a) Capacitor** b) Inductor c) Resistor d) All of these

Solution: For dc $v = 0$: $X_C = \frac{1}{0} = \infty$

6. If a wire cuts across a flux of 2×10^{-2} Wb in 0.1 s then the induced emf is

- a) 0.1 V b) 2 V **c) 0.02 V** d) 0.2 V

Solution: $e = \frac{d\phi}{dt} = \frac{2 \times 10^{-2}}{0.1} = 0.02 \text{ V}$

7. The Q-factor (quality factor) of an a.c, circuit containing a resistance L & capacitor C is

- a) $Q = \frac{1}{\sqrt{LC}}$ b) $Q = \frac{1}{R} \sqrt{\frac{C}{L}}$ **c) $Q = \frac{1}{R} \sqrt{\frac{L}{C}}$** d) $Q = \frac{1}{\sqrt{LCR}}$

8. The r.m.s value of an a.c voltage with a peak value of 311 V is

- a) 110 V **b) 220 V** c) 50 V d) 70.7 V

Solution: $E_{rms} = \frac{E_m}{\sqrt{2}} = 311 \times 0.707 = 220 \text{ V}$

9. The inductance L for which current is maximum in a series LCR circuit where $10 \mu \text{ F}$ capacitor and angular frequency of 1000 rad s^{-1} is

- a) 10 mH b) 1 mH **c) 100 mH** d) 0.1 mH

Solution: Frequency $f = \frac{1}{2\pi\sqrt{LC}}$; $\omega = \frac{1}{\sqrt{LC}}$

$$L = \frac{1}{\omega^2 C} = \frac{1}{(1000)^2 \times (10 \times 10^{-6})} = \mathbf{100 \text{ mH}}$$

10. A transformer is used to light a 100 W and 110 V bulb from 220 V mains. If the main circuit is 0.5 A then the efficiency of the transformer is

- a) 80 % **b) 90 %** c) 60 % d) 45 %

Solution: $\eta = \frac{P_{\text{out}}}{P_{\text{in}}} \times 100$; $P_{\text{in}} = 0.5 \times 220 = 110 \text{ W}$

$$\eta = \frac{100}{110} \times 100 \cong 90.9\% = \mathbf{90 \%}$$

11. The potential; difference across resistor, inductor and capacitance are 80V, 100V and 40 V respectively in an LCR circuit. The power factor of the circuit is

- a) 0.4 b) 0.5 **c) 0.8** d) 1.0

Solution:

$$V_R = 80 \text{ V} ; V_C = 40 \text{ V} ; V_L = 100 \text{ V}$$

$$\text{Power factors } \cos \phi = \frac{R}{Z} = \frac{V_R}{V}$$

$$\cos \phi = \frac{V_R}{\sqrt{V_R^2 + (V_L - V_C)^2}} = \frac{80}{\sqrt{6400 + 3600}} = \frac{80}{100} = \mathbf{0.8}$$

12. A circuit has resistance 30Ω , inductive reactance $X_L = 20 \Omega$ of a frequency of 50 Hz. If an A.C. source of 200V,100Hz is connected across the coil, the current flowing through it

- a) $\frac{20}{3} \text{ A}$ b) 2A **c) 4A** d) 8A

Solution: $f' = 100 \text{ Hz}$; $f' = 2f$; $X_L^1 = 2X_L$

$$Z = \sqrt{900 + 1600} = 50. I = \frac{V_0}{Z} = \frac{200}{50} = \mathbf{4A}$$

13. Which of the following terms remains same in a practical transformer?

- a) power b) current **c) frequency** d) voltage

14. A rectangular coil of 100 turns and size $0.1 \text{ m} \times 0.05 \text{ m}$ is placed perpendicular to a magnetic field of 0.1 T. If the field drops to 0.05 T in 0.05 s, the magnitude of the emf induced in the coil is

- a) 0.5 V** b) 0.75 V c) 1.0 V d) 1.5 V

$$\text{Solution: } \varepsilon = -\frac{NA(B_f - B_i)}{t} = -\frac{100 \times 0.1 \times 0.05 \times (0.05 - 0.1)}{0.05} = \mathbf{0.5 \text{ V}}$$

15. A wire of length 1 m moves with a speed of 10 ms^{-1} , perpendicular to a magnetic field. If the emf induced in the wire is 1V, the magnitude of the field is

- a) 0.01 T **b) 0.1 T** c) 0.2 T d) 0.02 T

$$\text{Solution: } \varepsilon = Blv = B = \frac{\varepsilon}{lv} = \frac{1}{1 \times 10} = \mathbf{0.1 \text{ T}}$$

16. A coil of area 10 cm^2 , 10 turns and resistance 20Ω is placed in a magnetic field directed perpendicular to the plane of the coil and changing at the rate of $10^8 \text{ gauss/second}$. The induced current in the coil will be

- a) 5 A b) 0.5 A c) 0.005 A d) 50 A

Solution: $\varepsilon = \frac{d}{dt}(NAB) = NA \frac{dB}{dt} = 10 \times 10 \times 10^{-4} \times 10^4 = 100 \text{ V}$

$$I = \frac{\varepsilon}{R} = \frac{100}{20} = 5 \text{ A}$$

17. A coil of cross – sectional area 400 cm^2 having 30 turns is making 1800 rev/min in a magnetic field of it. The peak value of the induced emf is

- a) 113 V **b) 226 V** c) 339 V d) 452 V

Solution: $\varepsilon_m = NBA \omega = 30 \times 1 \times 400 \times 10^{-4} \times 30 \times 2\pi = 226 \text{ V}$

18. The self – inductance of a coil is 5H and a current of 1 A changes to 2 A within 5 s through the coil. The value of induced emf will be

- a) 10 V b) 0.1 V **c) 1.0 V** d) 100 V

Solution: $|\varepsilon| = \left| L \frac{di}{dt} \right| = 5 \times \left(\frac{2-1}{5} \right) = 1.0 \text{ V}$

19. In an AC Circuit with capacitor only, if the frequency of the signal is zero then the capacitive reactance is

- a) **Infinity** b) zero
c) finite maximum d) finite minimum

Solution: $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$ $\nu = 0$ which means $X_C = \frac{1}{0} = \infty$

20. If N is the number of turns in a coil, the value of self – inductance varies as,

- a) N° b) N **c) N^2** d) N^{-2}

Solution: According to self inductance of long solenoid $L = \frac{\mu_0 N^2 A}{l} \Rightarrow L \propto N^2$

21. A 40Ω electric heater is connected to 200 V, 50 Hz main supply. The peak value of the electric current flowing in the circuit is approximately

- a) 2.5 A b) 5A **c) 7A** d) 10 A

Solution: $I_0 = \frac{V_0}{R} = \frac{200\sqrt{2}}{40} = 5\sqrt{2} \approx 7 \text{ A}$

22. The impedance of a circuit consists of 3Ω resistance and 4Ω resistance. The power factor of the circuit is

- a) 0.4 **b) 0.6** c) 0.8 d) 1.0

Solution: $\tan \phi = \frac{4}{3}$; Power factor = $\cos \phi = \frac{3}{5} = 0.6$

23. The power in AC circuit is given by $P = V_{\text{rms}} I_{\text{rms}} \cos \phi$. the value of the power factor $\cos \phi$ in series LCR circuit at resonance is

- a) Zero **b) 1** c) $\frac{1}{2}$ d) $\frac{1}{\sqrt{2}}$

Solution: $\cos \phi = \frac{R}{Z} = \frac{R}{\sqrt{R^2 + (X_L - X_C)^2}} = \frac{R}{R} = 1$

24. In a series LCR circuit $R = 10\Omega$ and the impedance $Z = 20\Omega$. Then the phase difference between the current and the voltage is

- a) 60°** b) 30° c) 45° d) 90°

Solution: $\cos \phi = \frac{R}{Z} = \frac{10}{20} = \frac{1}{2} = \phi = 60^\circ$

25. What is the value of inductance L for which the current is maximum in a series LCR circuit with $C = 10\mu\text{F}$ and $\omega = 1000\text{ s}^{-1}$?

- a) 1 mH b) 10 Mh
c) 100 mH d) cannot be calculated unless R is known

Solution:

$$L = \frac{1}{\omega^2 C} = \frac{1}{(1000)^2 \times 10 \times 10^{-6}} = 0.1\text{ H} = \mathbf{100\text{ mH}}$$

26. An emf of 12 V is induced when the current in the coil changes from 2 A to 6 A in 0.5 s. The coefficient of self – induction of the coil is

- a) 1.5 H** b) 6 H c) 0.3 H d) 30 H

Solution: $L = \frac{-\varepsilon}{di/dt} = \frac{12}{6-2/0.5} = \frac{6}{4} = 1.5\text{ H}$

27. In an a.c. circuit with an inductor

- a) Voltage lags current by $\pi/2$ b) voltage and current are in phase
c) voltage leads current by π **d) current lags voltage by $\pi/2$**

28. The unit of henry can also be written as

- a) V As^{-1} b) $\text{Wb}^{-1}\text{ A}$ **c) $\Omega\text{ s}$** d) all of these

29. The generator rule is

- a) Fleming's left hand rule **b) Fleming's right hand rule**
b) Maxwell's right hand corkscrew rule d) Right hand palm rule

30. The power loss is less in transmission line when

- a) voltage is less but current is more b) both voltage and current are more
c) voltage is more but current is less d) both voltage and current are less

31. In an a.c. circuit, the current $I = I_o \sin(\omega t - \frac{\pi}{2})$ lags behind the e.m.f

$e = E_o \sin(\omega t + \frac{\pi}{2})$ by

- a) 0 b) $\pi/4$ c) $\pi/2$ **d) π**

Solution: $\phi = \frac{\pi}{2} - \left(-\frac{\pi}{2}\right) = \pi$

32. A coil of area of cross – section 0.5m^2 with 10 turns is in a plane which is perpendicular to a uniform magnetic field of 0.2 Wb/m^2 . The magnetic flux through the coil is

- a) 100 Wb b) 10 Wb **c) 1 Wb** d) zero

Solution: $\phi_B = NBA \cos \theta = 0.5 \times 10 \times 0.2 \times \cos 0 = 1\text{Wb}$

33. An e.m.f of 12V is induced when the current in the coil changes at the rate of 40 As^{-1} . The Coefficient of self – induction of the coil is

- a) 0.3 H** b) 0.003 H c) 30 H d) 4.8 H

Solution: $L = \frac{\epsilon}{di/dt} = \frac{12}{40} = 0.3\text{H}$

34. In a three phase AC generator by three coils are fastened rigidly together and are displaced from each other by an angle

- a) 90° b) 180° **c) 120°** d) 360°

35. The r.m.s. value of the alternating current flowing through a resistor is 5A.its peak value is

- a) 3.536 A b) 70.7 A **c) 7.07A** d) 7A

Solution: $I_m = \sqrt{2} I_{\text{rms}} = 1.414 \times 5 = 7.07 \text{ A}$

36. In an A.c. circuit average power consumed is 200 W and the apparent power is 300 W. the power factor is

- a) 1.5 **b) 0.66** c) 0.33 d) 1

Solution: $\cos \phi = \frac{P_{\text{av}}}{P_{\text{app}}} = \frac{200}{300} = 0.66$

37. The effective value of alternating current is

- a) $\frac{I_0}{2}$ **b) $\frac{I_0}{\sqrt{2}}$** c) $I_0 \sqrt{2}$ d) $2 I_0$

38. In an A.C. Circuit

a) the average value of current is zero

b) the average value of square of current is zero

c) the average power dissipation is zero

d) the rms current is $\sqrt{2}$ times of peak current

39. In an a.c. circuit, the current leads the voltage by a phase of $\frac{\pi}{2}$, then the circuit has

a) Only an inductor (L) **b) only a capacitor (C)**

c) only a resistor (R) d) L, C and R in series

40. The resonant frequency of RLC circuit is γ_0 The inductance is doubled. The capacitance is also doubled. Now the resonant frequency of the circuit is

a) $2Y_0$

b) $\frac{Y_0}{2}$

c) $\frac{Y_0}{4}$

d) $\frac{Y_0}{\sqrt{2}}$

41. When the frequency of an a.c. circuit increases, the capacitive reactance offered by capacitor connected in the circuit

a) increases

b) **decreases**

c) remains the same

d) becomes zero

Solution: $X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C}$; $X_C \propto \frac{1}{\nu}$

42. The coefficient of self – induction of a solenoid is independent of

a) the number of turns in coil

b) the area of cross – section of the coil

c) the length of the coil

d) **the current passing through the coil.**

Solution:

$$L = \mu n^2 A l \left(\because n = \frac{N}{l} \right), L = \frac{\mu_0 N^2 A}{l}; L = \mu_0 \mu_r n^2 A l$$

43. The instantaneous emf and current equations of an a.c circuit are respectively $e = 200 \sin (\omega t + \pi/3)$ and $i = 10 \sin \omega t$ The average power consumed over one complete cycle is:

a) 2000 W

b) 1000 W

c) **500 W**

d) 707 W

Solution: $P_{av} = \frac{V_m I_m}{2} \cos \Phi = \frac{10 \times 200 \times \cos \frac{\pi}{3}}{2} = 500W$

44. If an emf of 25V is induced when the current in the coil changes at the rate of 100 As^{-1} , then the coefficient of self induction of the coil is :

a) 0.3 H

b) **0.25 H**

c) 2.5 H

d) 0.25 mH

Solution: $L = \frac{\epsilon}{di/dt} = \frac{25}{100} = 0.25 \text{ H}$

45. A DC of 5A produces the same heating effect as an AC of

a) 50 A rms current

b) 5A peak current

c) **5A rms current**d) $5/\sqrt{2}$ A peak current

46. In an A.C Circuit, the instantaneous values of emf and current are respectively

$$e = 200 \sin \left(\left(\omega t - \frac{\pi}{3} \right) \right) \& i = 10 \sin (\omega t + \pi/6)$$

(a) voltage lags behind current by a phase angle of $\pi/3$ (b) current leads voltage by a phase angle of $\pi/6$ (c) **Current leads voltage by a phase angle of $\pi/2$** (d) voltage leads current by a phase angle of $\pi/2$

Solution: Phase difference $= -\frac{\pi}{3} - \left(\frac{\pi}{6} \right) = -\frac{\pi}{6}$

47. The self – inductance of a straight conductor is

- a) Zero **b) infinity** c) very large d) very small

48. If the flux associated with a coil varies at the rate of 1 Wb/minute then the induced e.m.f. is

- a) 1V **b) 1/60 V** c) 60 V d) 0.60 V

Solution: $\varepsilon = -\frac{d}{dt}(\Phi_B) = \frac{1 \text{ Wb}}{60 \text{ sec}} = \frac{1}{60}$

49. The average power consumed over one cycle in an a.c. circuit is

- a) $E_{\text{rms}} I_{\text{rms}}$ **b) $E_{\text{rms}} I_{\text{rms}} \cos \phi$** c) $E_{\text{rms}} I_{\text{rms}} \sin \phi$ d) $E_0 I_0$

50. In LCR circuit when $X_L = X_C$ the current

- a) is zero **b) is in phase with the voltage**
c) leads the voltage d) lags behind the voltage

51. In a step – up transformer the input voltage is 220 V and the output voltage is 11 kV. The ratio of number of turns of primary to secondary is

- a) 50 : 1 **b) 1 : 50** c) 25 : 1 d) 1 : 25

Solution: $\frac{N_p}{N_s} = \frac{E_p}{E_s} = \frac{220}{11 \times 10^3} = \frac{1}{50}$

52. Which of the following cannot be stepped up in a transformer?

- a) Input current b) Input voltage **c) Input power** d) All of these

53. In LCR series a.c. circuit, the phase difference between current and voltage is 30° . The reactance of the circuit is 17.32Ω . The value of resistance is

- a) 30Ω** b) 10Ω c) 17.32Ω d) 1.732Ω

Solution: $R = \frac{(X_L - X_C)}{\tan \phi} = \frac{17.32}{\tan 30^\circ} = 30 \Omega$

54. In RLC series circuit, at resonance

- a) Current is minimum b) impedance is maximum
c) Circuit is purely inductive **d) current is in phase with the voltage**

55. Lenz's law is in accordance with the law of

- a) conservation of energy** b) conservation of charge
c) conservation of momentum d) conservation of angular momentum

Short Answers - Book Back

1. What is meant by electromagnetic induction?

- ✓ Whenever the **magnetic flux** linked with a closed coil **changes**, an **emf** is induced and hence an electric current flows in the circuit.
- ✓ This current is called an induced current and the emf giving rise to such current is called an induced emf.

- ✓ This phenomenon is known as electromagnetic induction.

2.State Faraday's law of electromagnetic induction.

First law

Whenever **magnetic flux** linked with a closed circuit **changes**, an **emf** is induced in the circuit which lasts in the circuit as long as magnetic flux is changing.

Second law

The magnitude of induced emf in a closed circuit is equal to the time rate of change of magnetic flux linked with the circuit.

3.State Lenz's law

It states that the direction of the induced current is such that it always opposes the cause responsible for its production.

4.State Fleming's right hand rule

The thumb, index finger and middle finger of right hand stretched out in mutually perpendicular direction .If the **index finger** points the **direction of the magnetic field** and the **thumb** indicates the **direction of motion of the conductor**, then the **middle finger** will indicate the **direction of the induced current**.

5.How is Eddy current is produced? How do they flow in a conductor?

- ✓ For a conductor in the form of a sheet or plate, an emf is induced when magnetic flux linked with it changes.
- ✓ The induced currents flow in concentric circular paths
- ✓ As these electric currents resemble eddies of water, these are known as Eddy currents or Foucault current

6.Mention the ways of producing induced emf .

$$\varepsilon = \frac{d}{dt}(BA\cos\theta)$$

- (i) By changing the magnetic field B.
- (ii) By changing the area A of the coil.
- (iii) By changing the relative orientation θ of the coil with magnetic field.

7.What for an inductor is used? Give some examples

Inductor is a device used to store energy in a magnetic field when an electric current flows through it.

Examples: coils, solenoids and toroids

8. What do you mean by self-induction?

- ✓ An electric current flowing through a coil will set up a magnetic field around it. Therefore, the magnetic flux of the magnetic field is linked with that coil itself. If this flux is changed by changing the current, an emf is induced in that same coil.
- ✓ This phenomenon is known as self-induction.

9. How will you define the unit of inductance?

Inductance of the coil is one henry if a current changing at the rate of 1 A s^{-1} induces an opposing emf of 1 V in it.

10. What do you understand by self-inductance of a coil? Give its physical significance.

Self-inductance: It is defined as flux linkage with the coil when 1A current flows through it.

Physical significance: Inductance of the coil opposes any change in current and tries to maintain the original state.

11. What is meant by mutual induction?

When an electric current passing through a coil changes with time, an emf is induced in the neighbouring coil. This phenomenon is known as mutual induction and the emf is called mutually induced emf.

12. Give the principle of AC generator

- ✓ It works on the principle of **electro-magnetic induction**.
- ✓ The relative motion between a conductor and a magnetic field changes the magnetic flux linked with the conductor which in turn induces an emf.

13. List out the advantages of stationary armature – rotating field system of AC generator

- 1) The current is drawn **directly from fixed terminals** on the stator without the use of brush contacts.
- 2) The **insulation** of stationary armature winding is **easier**.

- 3) The number of **sliding contacts** (slip rings) is **reduced**.
- 4) **Armature windings** can be constructed **more rigidly** to prevent deformation due to any mechanical stress.

14. What are step up and step down transformer?

Step up transformer converts an ac with **low voltage into an ac with high voltage** and decrease the corresponding current.

Step up transformer: $k > 1$, $N_s > N_p$, $V_s > V_p$, $I_s < I_p$

Step down transformer converts an ac with **high voltage into an ac with low voltage** and increase the corresponding current.

Step down transformer: $k < 1$, $N_s < N_p$, $V_s < V_p$, $I_s > I_p$

15. Define average value of an alternating current

It is defined as average of all values of current over a positive half cycle or negative half cycle.

$$I_{av} = 0.6371 I_M$$

16. How will you define RMS value of alternating current?

- ✓ RMS value of alternating current is defined as square root of mean of squares of all the current over one cycle.

17. What are phasors?

A sinusoidal alternating voltage (or current) can be represented by a vector which rotates about the origin in anti-clockwise direction at a constant angular velocity ω . Such a rotating vector is called a phasor.

18. Define electrical resonance

- ✓ When the frequency of the applied alternating source is equal to the natural frequency of the RLC circuit, the current in the circuit reaches its maximum value.
- ✓ Then the circuit is said to be in electrical resonance.

19. What do you mean by resonant frequency?

- ✓ When the frequency of the applied alternating source (ω_r) is equal to the natural frequency of the RLC circuit $\left(\frac{1}{\sqrt{LC}}\right)$, the current in the circuit reaches its maximum value.

- ✓ Then the circuit is said to be in electrical resonance. The frequency at which resonance takes place is called resonant frequency.

20. How will you define Q-factor?

It is defined as the ratio of voltage across L or C to the applied voltage.

$$\text{Q-factor} = \frac{\text{Voltage across L or C at resonance}}{\text{Applied voltage}} = \frac{1}{R} \sqrt{\frac{L}{C}}$$

21. What is meant by wattless current?

- ✓ The current in the AC circuit is said to be wattless current if the **power consumed by it is zero**
- ✓ $\phi = \frac{\pi}{2} \rightarrow P_{av} = V_{RMS} I_{RMS} \cos \frac{\pi}{2} = 0$

22. Give any one definition of power factor

It is defined as the ratio of true power to the apparent power of an ac circuit.

Or

It is equal to the cosine of the phase angle between current and voltage in the a.c circuit

$$\text{Power factor} = \frac{\text{True power}}{\text{Apparent power}}$$

23. What are LC oscillations?

Whenever energy is given to a circuit containing a pure inductor of inductance L and a capacitor of capacitance C, the energy oscillates back and forth between the magnetic field of the inductor and the electric field of the capacitor. Thus the electrical oscillations of definite frequency are generated. These oscillations are called LC oscillations.

Short Answers - Book Inside

1. A straight conducting wire is dropped horizontally from a certain height with its length along east – west direction. Will an emf be induced in it? Justify your answer.

Yes! An emf will be induced in the wire because it moves perpendicular to the horizontal component of Earth's magnetic field.

2. Why resonance not occur in a RL and RC circuits.?

- ✓ The phenomenon of electrical resonance is possible when the circuit contains both L and C.

- ✓ Only then the voltage across L and C cancel one another when V_L and V_C are 180° out of phase and the circuit becomes purely resistive.

3. What is undamped oscillation?

In the ideal LC circuit, there is no loss of energy. Therefore, the oscillations will continue indefinitely. Such oscillations are called undamped oscillations.

4.A capacitor allow AC but blocks DC why?

Capacitive reactance: $X_c = \frac{1}{2\pi f c}$

For DC: $f = 0 \therefore X_c = \infty$. For AC: $X_c = \frac{1}{f}$

Therefore a **capacitive circuit offers infinite resistance** to the steady current DC.

4. What is meant by wattful current?

- ✓ The component of current ($I_{RMS} \cos\phi$) which is in phase with the voltage is called active component.
- ✓ The current in the AC circuit is said to be wattful current if the power consumed by it is $V_{RMS} I_{RMS}$

5.What are advantages of three phase generator?

- 1) For a given dimension of the generator, three-phase machine produces **higher power output** than a single-phase machine.
- 2) For the same capacity, three-phase alternator is **smaller in size** when compared to single phase alternator.
- 3) Three-phase transmission system is **cheaper**. A relatively thinner wire is sufficient for transmission of three-phase power.

6.What do you meant by efficiency of transformer

- ✓ The efficiency η of a transformer is defined as the ratio of the useful output power to the input power

$$\eta = \frac{\text{output power}}{\text{input power}} \times 100$$

7.Give the Advantages of AC over DC

- 1) The **generation** of AC is **cheaper** than that of DC.
- 2) When AC is supplied at higher voltages, the **transmission losses are small** compared to DC transmission.
- 3) **AC** can easily be converted into **DC** with the help of rectifiers.

8. Give the Disadvantages of AC

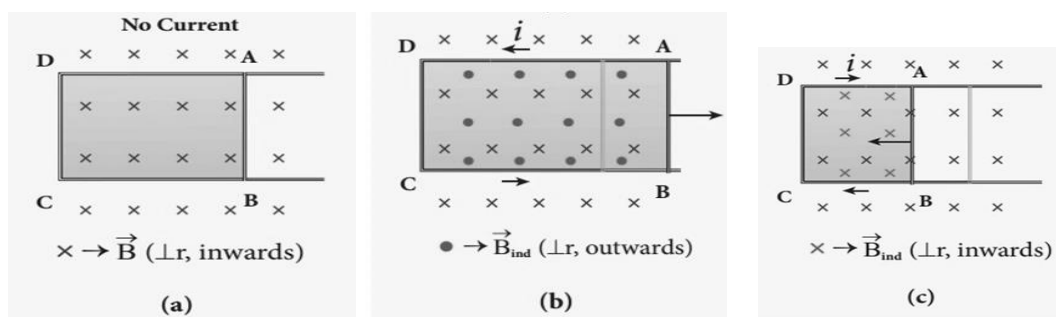
- ✓ Alternating voltages cannot be used for certain applications e.g. charging of batteries, electroplating, electric traction etc.
- ✓ At high voltages, it is more **dangerous to work** with AC than DC

Long Answers – Book Back

1. Establish the fact that the relative motion between the coil and the magnet induces an emf in the coil of closed circuit.

- ✓ When a bar magnet is placed close to a coil, some of the magnetic field lines of the bar magnet pass through the coil i.e., the magnetic flux is linked with the coil.
- ✓ When the bar magnet and the coil approach each other, the magnetic flux linked with the coil increases.
- ✓ So increase in magnetic flux induces an emf and hence a transient electric current flows in the circuit in one direction
- ✓ At the same time, when they recede away from one another, the magnetic flux linked with the coil decreases.
- ✓ The decrease in magnetic flux again induces an emf in opposite direction and hence an electric current flows in opposite direction.
- ✓ So there is deflection in the galvanometer which indicates current is induced when there is a relative motion between the coil and the magnet.
- ✓ Whenever the magnetic flux linked with a closed coil changes, an emf (electromotive force) is induced and hence an electric current flows in the circuit. This current is called an induced current and the emf giving rise to such current is called an induced emf. This phenomenon is known as electromagnetic induction.

2. Give an illustration of determining direction of induced current by using Lenz's law



- ✓ Consider a uniform magnetic field, with its field lines perpendicular to the plane of the paper and pointing inwards.

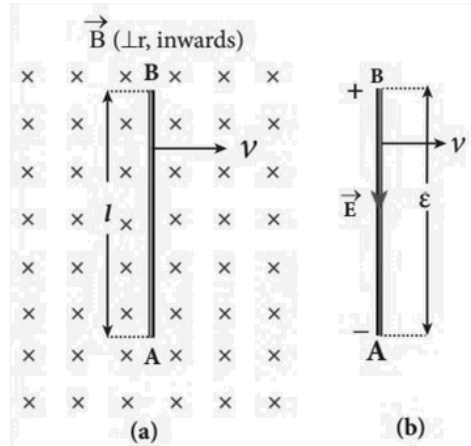
- ✓ A rectangular metallic frame ABCD is placed in this magnetic field, with its plane perpendicular to the field. The arm AB is movable so that it can slide towards right or left.
- ✓ If the arm AB slides to our right side, the number of field lines (magnetic flux) passing through the frame ABCD increases and a current is induced.
- ✓ By Lenz's law, the induced current opposes this flux increase and it tries to reduce it by producing another magnetic field pointing outwards i.e., opposite to the existing magnetic field.
- ✓ From the direction of the magnetic field thus produced, the direction of the induced current is found to be anti-clockwise by using right-hand thumb rule.
- ✓ The leftward motion of arm AB decreases magnetic flux. The induced current, this time, produces a magnetic field in the inward direction i.e., in the direction of the Existing magnetic field.
- ✓ Therefore, the flux decrease is opposed by the flow of induced current. From this, it is found that induced current flows in clockwise direction.

3. Show that Lenz's law is in accordance with the law of conservation of energy.

- ✓ According to Lenz's law, when a magnet is moved either towards or away from a coil, the induced current produced opposes its motion.
- ✓ As a result, there will always be a resisting force on the moving magnet.
- ✓ Work has to be done by some external agency to move the magnet against this resisting force. Here the mechanical energy of the moving magnet is converted into the electrical energy which in turn, gets converted into Joule heat in the coil i.e., energy is converted from one form to another.

4. Obtain an expression for Motional emf from Lorentz force

- ✓ Consider a straight conducting rod AB of length l in a uniform magnetic field $\vec{B}$ which is directed perpendicularly into the plane of the paper.
- ✓ Let the rod move with a constant velocity $\vec{v}$ towards right side.
- ✓ When the rod moves, the free electrons present in it also move with same velocity $\vec{v}$ in $\vec{B}$.



- ✓ As a result, the Lorentz force acts on free electrons in the direction from B to A and is given by the relation

$$\vec{F}_B = -e(\vec{v} \times \vec{B})$$

- ✓ Due to the electric field the coulomb force starts acting on the free electrons along AB and is given by

$$\vec{F}_E = -e\vec{E}$$

- ✓ At equilibrium, the magnetic Lorentz force and the coulomb force balance each other and no further accumulation of free electrons at the end A takes place.

$$|\vec{F}_B| = |\vec{F}_E|$$

$$|-e(\vec{v} \times \vec{B})| = |-e\vec{E}|$$

$$vB\sin 90^\circ = E$$

$$vB = E \text{ ----(1)}$$

The potential difference between two ends of the rod is $V = El$

From (1) $V = vBl$

Lorentz force on the free electrons is responsible to maintain this potential difference and hence produces an emf.

$$\epsilon = Blv$$

As this emf is produced due to the movement of the rod, it is often called as motional emf.

5. Give the uses of Foucault current (or) Eddy current

i. Induction stove

- 1) It is used to **cook the food quickly** and safely with less energy consumption.
- 2) Below the cooking zone, there is a tightly wound coil of insulated wire.
- 3) The cooking pan made of suitable material, is placed over the cooking zone.
- 4) When the stove is switched on, an alternating current flowing in the coil produces high frequency alternating magnetic field which induces very strong eddy currents in the cooking pan.

- 5) The **eddy currents** in the pan produce so much of **heat due to Joule heating** which is used to cook the food.

ii. Eddy current brake

- 1) This eddy current braking system is generally used in high speed trains and roller coasters. Strong electromagnets are fixed just above the rails.
- 2) To stop the train, electromagnets are switched on.
- 3) The **magnetic field** of these magnets induces eddy currents in the rails which **oppose or resist the movement of the train**.
- 4) This is Eddy current circular brake.

iii. Electromagnetic damping

- 1) The armature of the galvanometer coil is wound on a soft iron cylinder.
- 2) Once the armature is deflected, the relative motion between the soft iron cylinder and the radial magnetic field induces eddy current in the cylinder.
- 3) The damping force due to the flow of eddy current brings the armature to rest immediately and then galvanometer shows a steady deflection.

6. Define self – inductance of a coil in terms of magnetic flux and induced emf

(i) Self – inductance of a coil in terms of magnetic flux

$$L = \frac{N\Phi_B}{i}$$

Self-inductance or simply inductance of a coil is defined as the **flux linkage of the coil when 1A current flows** through it.

(ii) Self – inductance of a coil in terms of induced emf

$$L = \frac{-\varepsilon}{di/dt} \mid \frac{di}{dt} = 1 \text{ A/s then } L = -\varepsilon$$

Self-Inductance of a coil is also defined as the **opposing emf** induced in the coil when the **rate of change of current through the coil is 1 A s^{-1}** .

7. Assuming that the length of the solenoid is large when compared to its diameter , find the equation for its inductance

- ✓ Consider a long solenoid of length l and cross-sectional area A .
- ✓ n - number of turns per unit length (or turn density) of the solenoid.

- ✓ When an electric current is passed through the solenoid, a magnetic field is produced by it which is almost uniform and is directed along the axis of the solenoid.

The magnetic field at any point inside the solenoid is

$$B = \mu_0 n i \text{ ----- (1)}$$

The magnetic flux passing through each turn is

$$\begin{aligned} \phi_B &= \int \vec{B} \cdot d\vec{A} = BA \cos\theta \\ &= BA \text{ (since } \theta = 0^\circ \text{)----- (2)} \end{aligned}$$

Sub B in (2)

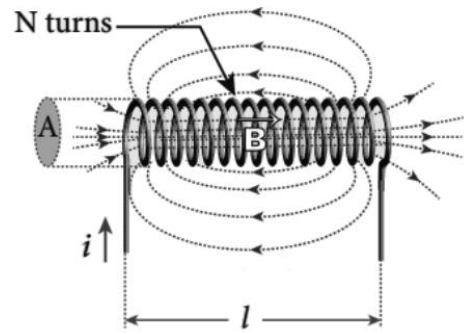
$$\phi_B = \mu_0 n i A$$

The total magnetic flux linked or flux linkage of the solenoid with N turns (the total number of turns N is given by

$$N = n l) \text{ is}$$

$$\begin{aligned} N\phi_B &= (nl)(\mu_0 n i)A \\ &= (\mu_0 n^2 A l)i \text{ ----- (2)} \end{aligned}$$

$$N\phi_B = Li \text{ ----- (3)}$$



Comparing (2) & (3)

$$Li = (\mu_0 n^2 A l)i$$

$$L = \mu_0 n^2 A l$$

If the solenoid is filled with a dielectric medium of relative permeability

$$L = \mu n^2 A l$$

8. An inductor of inductance L carries an electric current I. How much energy is stored while establishing the current in it

- ✓ Whenever a current is established in the circuit, the inductance opposes the growth of the current.
- ✓ In order to establish a current in the circuit, work is done against this opposition by some external agency.
- ✓ This work done is stored as magnetic potential energy.
- ✓ Let us assume that electrical resistance of the inductor is negligible and inductor effect alone is considered.

The induced emf at any instant t is

$$\varepsilon = -L \frac{di}{dt} \text{ ----- (1)}$$

Let dW be work done in moving a charge dq in a time dt against the opposition, then

$$dW = V dq \text{ ----- (2)}$$

$$V = -\varepsilon, dq = i dt$$

Sub V & dq values in (2) equation

$$dW = -\varepsilon i dt$$

$$\text{Sub } \varepsilon = -L \frac{di}{dt} \text{ in above equation}$$

$$= - \left(-L \frac{di}{dt} \right) dt$$

$$dW = L i di$$

$$W = \int_0^i L i di$$

$$W = \frac{1}{2} Li^2$$

This work done is stored as magnetic potential energy $U_B = \frac{1}{2} Li^2$

9. Show that the mutual inductance between a pair of coils is same ($M_{12} = M_{21}$)

Mutual induction

- ✓ Consider two coils which are placed close to each other. If an electric current i_1 is sent through coil 1, the magnetic field produced by it is also linked with coil 2.
- ✓ Φ_{21} -magnetic flux linked with each turn of the coil 2 of N_2 turns due to coil 1.

$$N_2 \Phi_{21} \propto i_1$$

$$N_2 \Phi_{21} = M_{21} i_1$$

$$\epsilon_2 = - \frac{d(N_2 \Phi_{21})}{dt}$$

Sub $N_2 \Phi_{21} = M_{12} i_1$ in above equation

$$\epsilon_2 = - M_{21} \frac{di_1}{dt}$$

$$M_{21} = \frac{-\epsilon_2}{\frac{di_1}{dt}}$$

$$\frac{di_1}{dt} = 1 \text{ As}^{-1}$$

$$\text{Then } M_{12} = -\epsilon_2$$

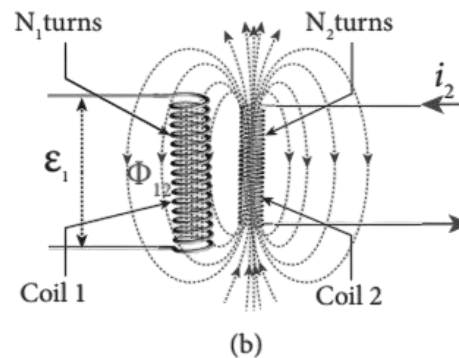
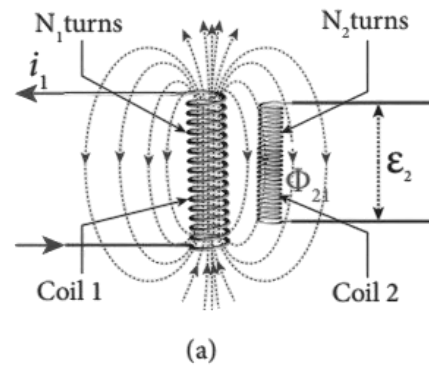
Similarly

$$N_1 \Phi_{12} = M_{12} i_2$$

$$M_{12} = \frac{-\epsilon_1}{\frac{di_2}{dt}}$$

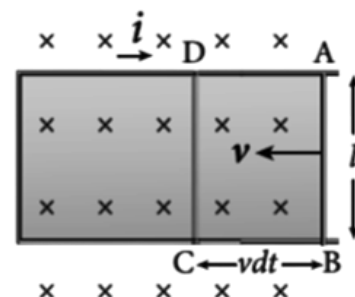
$$\frac{di_2}{dt} = 1 \text{ As}^{-1}$$

$$M_{12} = M_{21} = M$$



10. How will you induce an emf by changing the area enclosed by the coil?

- ✓ Consider a conducting rod of length l moving with a velocity $\vec{v}$ towards left on a rectangular metallic framework.
- ✓ The whole arrangement is placed in a uniform magnetic field $\vec{B}$ whose magnetic lines are perpendicularly directed into the plane of the paper.



- ✓ As the rod moves from AB to DC in a time dt , the area enclosed by the loop and hence the magnetic flux through the loop decreases.

- ✓ The change in magnetic flux in time dt is $d\phi_B = B \times dA$ -----(1)

dA = area of ABCD

area of ABCD(rectangle) = $l \times b$ ----- (2)

$$v = \frac{dx}{dt} = \frac{b}{dt} \quad (\text{where } dx = b)$$

$$b = vdt$$

Sub b values in (2)

$$dA = l \times vdt \text{ ----- (3)}$$

Comparing (4) & (5)

$$\varepsilon = Blv$$

This emf is motional emf.

Sub (3) in (1)

$$\frac{d\phi_B}{dt} = Blv \text{ ----- (4)}$$

As a result of change in flux , induced emf is generated in the loop

$$\varepsilon = \frac{d\phi_B}{dt} \text{ ----- (5)}$$

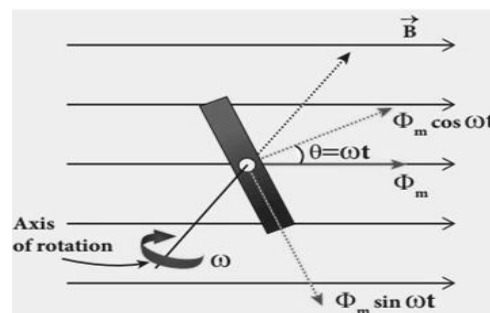
11.Show mathematically that the rotation of a coil in a magnetic over one rotation induces an alternating emf of one cycle

- 1) Consider a rectangular coil of N turns kept in magnetic field $\vec{B}$.
- 2) It is rotated in anticlockwise direction with an angular velocity ω about an axis perpendicular to field.
- 3) At time = 0, the plane of the coil is perpendicular to the field and the flux linked with the coil has its maximum value $\phi_m = BA$
- 4) In a time t seconds, the coil is rotated through an angle ($\theta = \omega t$) in anti-clockwise direction. In this position, the flux linked is $\Phi_m \cos \omega t$, a component of Φ_m normal to the plane of the coil
- 5) The component parallel to the plane ($\Phi_m \sin \omega t$) has no role in electromagnetic induction. Therefore, the flux linkage at this deflected position is

$$N\phi_B = NBA \cos \omega t$$

$$\varepsilon = - \frac{d}{dt} (N\phi_B)$$

$$\begin{aligned} \varepsilon &= - \frac{d}{dt} (NBA \cos \omega t) \\ &= NBA \omega \sin \omega t \text{ ----- (1)} \end{aligned}$$



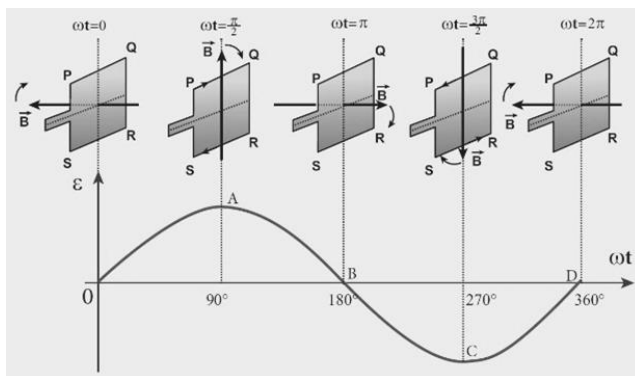
Maximum value of induced emf is

$$\epsilon_m = NBA\omega$$

Therefore, the value of induced emf at that instant is then given by

$$\epsilon = \epsilon_m \sin \omega t$$

- ✓ Induced emf varies as sine function of the time angle ωt .
- ✓ The graph between induced emf and time angle for one rotation of coil will be a sine curve and the emf varying in this manner is called sinusoidal emf or alternating emf.
- ✓ Thus rotation of a coil in a magnetic over one rotation induces an alternating emf of one cycle.



12. Elaborate the standard construction details of AC generator

It consists of two major parts – stator and rotor

- 1) Stator – Stationary
- 2) Rotor – Rotates inside the stator
- 3) Armature winding is mounted on stator
- 4) Field magnet mounted on rotor

Construction details of

i) Stator

- ✓ The **stationary part** which has armature windings mounted in it is called stator.
- ✓ It has two components, namely **stator core** and **armature winding**.

Stator core

- ✓ Stator core or armature core is made up of iron or steel alloy.
- ✓ It is a hollow cylinder and is laminated to minimize eddy current loss.
- ✓ The slots are cut on inner surface of the core to accommodate armature windings.

Armature winding

- ✓ Armature winding is the coil, wound on slots provided in the armature core.

ii) Rotor

- 1) Rotor contains **magnetic field windings**.
- 2) The magnetic poles are **magnetized by DC source**.
- 3) The ends of field windings are connected to a pair of slip rings, attached to a common shaft about which rotor rotates.
- 4) Slip rings rotate along with rotor.

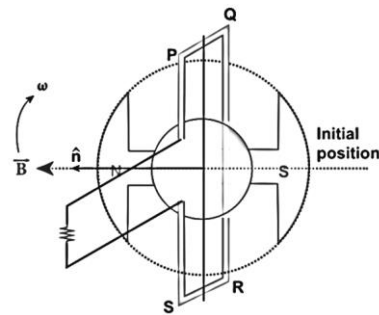
- 5) To maintain connection between the DC source and field windings, two brushes are used which continuously slide over the slip rings.

13.Explain the working of single – phase AC generator with necessary diagram

- ✓ In a single phase AC generator, the armature conductors are connected in series so as to form a single circuit which generates a single-phase alternating emf and hence it is called single-phase alternator
- ✓ single-turn rectangular loop PQRS is mounted on the stator.
- ✓ Field winding is fixed inside the stator and it can be rotated about an axis, perpendicular to the plane of paper

Working

1. The loop PQRS is stationary and is perpendicular to the plane of the paper.
2. When field windings are excited, magnetic field is produced around it.
3. Let the field magnet be rotated in clockwise direction by the prime mover.
4. The axis of rotation is perpendicular to the plane of the paper.
5. Assume that initial position of the field magnet is horizontal.
6. At that instant, the direction of magnetic field is perpendicular to the plane of the loop PQRS.
7. The induced emf is zero
8. When field magnet rotates through 90° , magnetic field becomes parallel to PQRS.
9. The induced emf's across PQ and RS would become maximum.
10. Since they are connected in series, emfs are added up and the direction of total induced emf is given by Fleming's right hand rule.
11. The direction of the induced emf is at right angles to the plane of the paper.
12. For PQ, it is downwards and for RS upwards. Therefore, the current flows along PQRS.
13. For the rotation of 180° from the initial position, the field is again perpendicular to PQRS and the induced emf becomes zero. This is represented by point B.



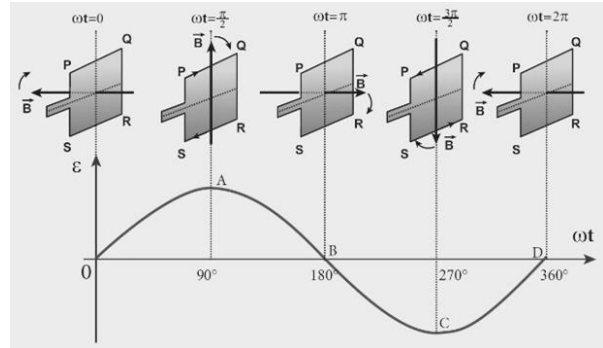
14. The field magnet becomes again parallel to PQRS for 270° rotation of field magnet.

The induced emf is maximum but the direction is reversed. Thus the current flows along SRQP. This is represented by point C.

15. On completion of 360° , the induced emf becomes zero and is represented by the point D. Emf induced in PQRS is alternating in nature.

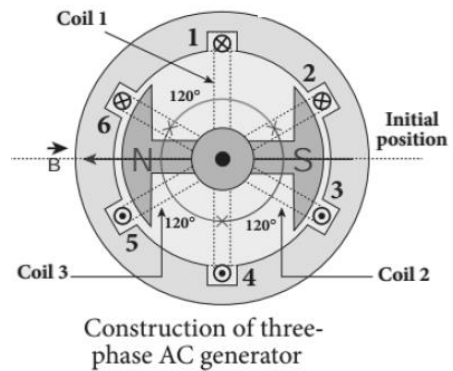
16. Therefore, when field magnet completes one rotation, induced emf in PQRS finishes one cycle.

17. The frequency of the induced emf depends on the speed at which the field magnet rotates.



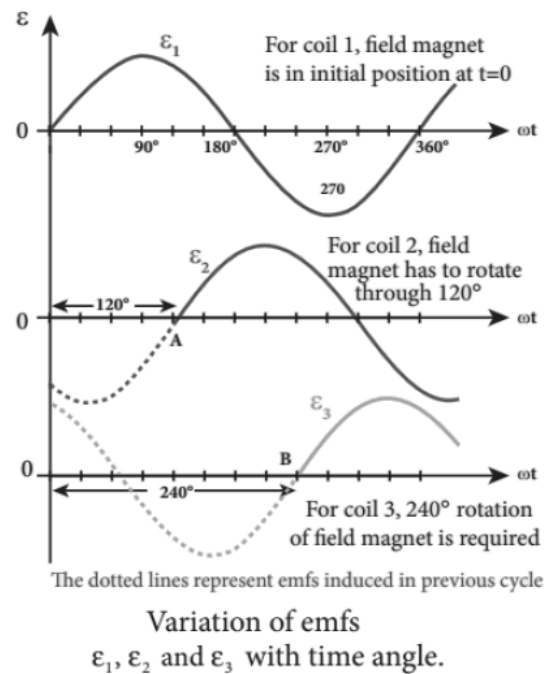
14. How are the three different emfs generated in a three-phase AC generator? Show the graphical representation of these three emfs.

- ✓ In three-phase AC generator, the armature core has 6 slots, cut on its inner rim.
- ✓ Each slot is 60° away from one another.
- ✓ Six armature conductors are mounted in these slots.
- ✓ The conductors 1 and 4 are joined in series to form coil 1.
- ✓ The conductors 3 and 6 form coil 2 while the conductors 5 and 2 form coil 3.
- ✓ So, these coils are rectangular in shape and are 120° apart from one another.



Working

- ✓ The initial position of the field magnet is horizontal and field direction is perpendicular to the plane of the coil 1.
- ✓ As it is seen in single phase AC generator, when field magnet is rotated from that position in clockwise direction, alternating emf ϵ_1 in coil 1 begins a cycle from origin O.
- ✓ The corresponding cycle for alternating emf ϵ_2 in coil 2 starts at point A after field magnet has rotated through 120° .
- ✓ Therefore, the phase difference between ϵ_2 and ϵ_1 is 120° . Similarly, emf ϵ_3 in coil 3 would begin its cycle at point B after 240° rotation of field magnet from initial position.
- ✓ Thus these emf's produced in the three phase AC generator have 120° phase difference between one another.



15.Explain the construction and working of transformer

Principle; Mutual induction between two coils.

Construction

1. There are two coils of high mutual inductance wound over the same transformer core.
2. The core is generally laminated and is made up of a good magnetic material like silicon steel.
3. The coil across which alternating voltage is applied is called primary coil P and the coil from which output power is drawn out is called secondary coil S.

Working

1. If the primary coil is connected to a source of alternating voltage, an alternating magnetic flux is set up in the laminated core.
2. Rate at which magnetic flux changes through each turn is same for both primary and secondary coils.
3. As a result of flux change, emf is induced in both primary and secondary coils.

4. The emf induced in the primary coil ε_p is almost equal to the applied voltage v_p and is given by $\varepsilon_p = -N_p \frac{d}{dt}(\phi_B)$

$$V_p = -N_p \frac{d}{dt}(\phi_B) \text{ ----(1)}$$

5. The frequency of alternating magnetic flux in the core is same as the frequency of the applied voltage.

6. The emf induced in the secondary coil ε_s

$$\text{is given by } \varepsilon_s = -N_s \frac{d}{dt}(\phi_B)$$

N_p, N_s – number of turns in the primary and secondary coil

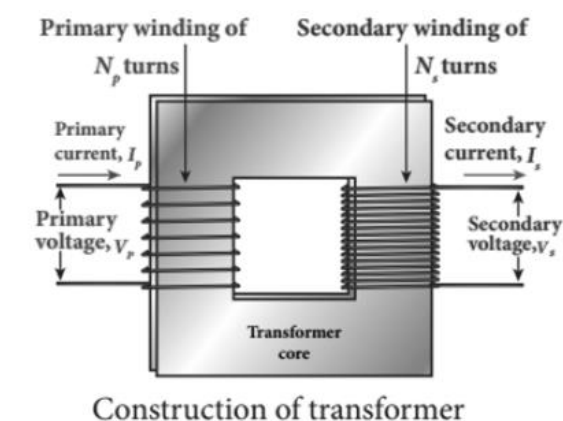
If the secondary circuit is open, then $\varepsilon_s = V_s$ where V_s is the voltage across secondary coil. V_s

$$= -N_s \frac{d}{dt}(\phi_B) \text{ ---- (2)}$$

Dividing (2) by (1)

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = K$$

K – voltage Transformer ratio



For an ideal transformer,

Input power = Output power

$$V_p I_p = V_s I_s$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s} = K$$

For step-up transformer: Voltage is increased & corresponding current is decreased.

$$K > 1, V_s > V_p, I_s < I_p$$

For step down transformer: Voltage is decreased and the current is increased.

$$K < 1, V_s < V_p, I_s > I_p$$

16. Mention the various energy losses in a transformer

i) Core loss or Iron loss

1. This loss takes place in **transformer core**.
2. Hysteresis loss and eddy current loss are known as core loss or Iron loss.
3. When transformer core is magnetized and demagnetized repeatedly by the alternating voltage applied across primary coil, hysteresis takes place due to which some energy is lost in the form of heat.

Hysteresis loss minimization - Using **steel of high silicon content** in making transformer core.

(ii) Eddy current loss

Alternating magnetic **flux in the core induces eddy currents** in it. Therefore, there is energy loss due to the flow of eddy current, called eddy current loss.

Eddy current minimization- using very thin laminations of transformer core.

(iii) Copper loss

1. Transformer windings have electrical resistance.
2. When an electric current flows through them, some **amount of energy is dissipated due to Joule heating**. This energy loss is called copper loss

Copper loss minimization - Using wires of larger diameter.

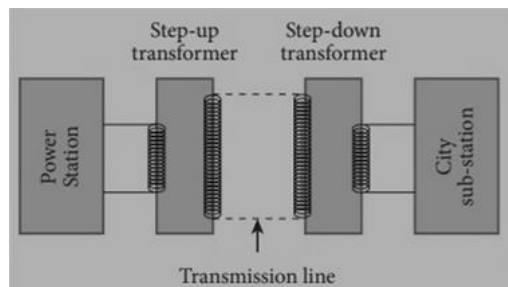
Flux leakage

Flux leakage happens when the magnetic lines of primary coil are not completely linked with secondary coil.

Flux leakage minimization - Using winding coils one over the other.

17. Give the advantage of AC in long distance power transmission with an example

- ✓ Electric power is produced in a large scale at electric power stations with the help of AC generators
- ✓ Most of power stations are located at remote places.
- ✓ Hence the electric power generated is transmitted over long distances through transmission lines to reach towns or cities where it is actually consumed. This process is called power transmission.
- ✓ A sizable fraction of electric power is lost due to Joule heating .
- ✓ Property of alternating voltage that it can be stepped up and stepped down by using transformers could be exploited in reducing current and thereby reducing power losses to a greater extent.
- ✓ At the transmitting point, the voltage is increased and the corresponding current is decreased by using step-up transformer Then it is transmitted through transmission lines. This reduced current at high voltage reaches the destination without any appreciable loss.
- ✓ At the receiving point, the voltage is decreased and the current is increased to appropriate values by using step-down transformer and then it is given to consumers.



✓ Thus power transmission is done efficiently and economically.

Case (i) A power of 11, 000 W is transmitted at 220 V

$$P = VI$$

$$I = \frac{V}{P} = \frac{220}{11000} = 50 \text{ A}$$

$$\text{Power loss} = I^2 R = 2500(R) \text{ watts}$$

Hence it is evident that if power is transmitted at a higher voltage loss of energy in the heat can be considerably reduced.

Case(ii) A power of 11, 000 W is transmitted at 22000 V

$$P = VI$$

$$I = \frac{V}{P} = \frac{22000}{11000} = 0.5 \text{ A}$$

$$\text{Power loss} = I^2 R = 0.25(R) \text{ watts}$$

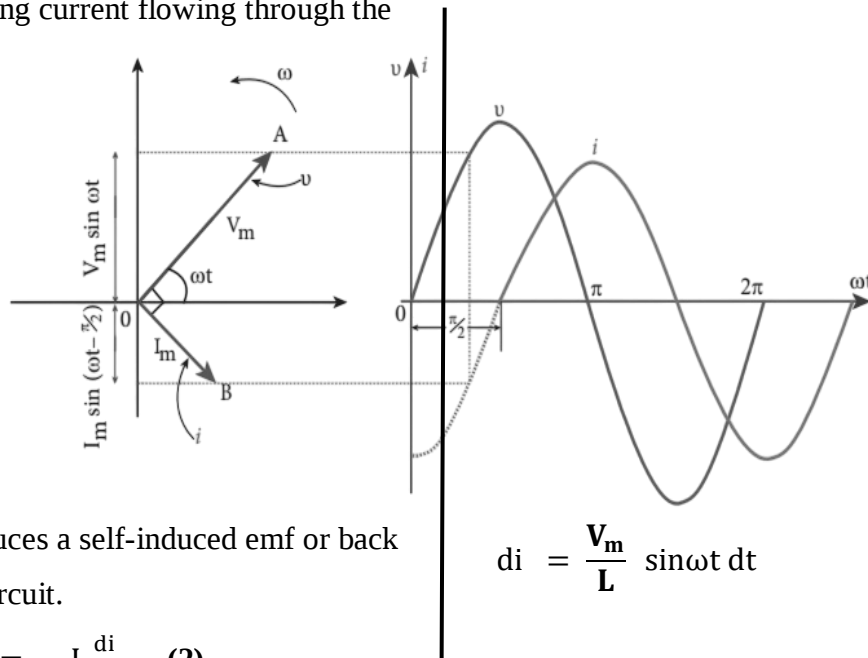
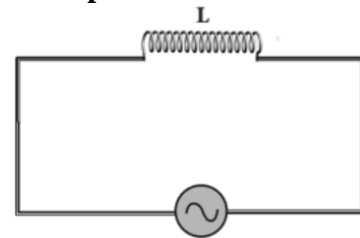
18. Find out phase relationship between voltage and current in a pure inductor circuit

Consider a circuit containing a pure inductor of inductance L connected across an alternating voltage source.

Alternating voltage is given by the equation $V = V_m \sin \omega t$

---- (1)

The alternating current flowing through the



inductor induces a self-induced emf or back emf in the circuit.

$$\text{Back emf } \varepsilon = -L \frac{di}{dt} \text{ ---- (2)}$$

By applying Kirchoff's loop rule to the purely inductive circuit, we get

$$V + \varepsilon = 0$$

$$V_m \sin \omega t - L \frac{di}{dt} = 0$$

$$V_m \sin \omega t = L \frac{di}{dt}$$

$$di = \frac{V_m}{L} \sin \omega t \, dt$$

Integrating both sides

$$I = \frac{V_m}{L} \int \sin \omega t \, dt = \frac{V_m}{L\omega} (-\cos \omega t) + \text{constant}$$

$$I = \frac{V_m}{L\omega} (\sin \omega t - \pi/2)$$

$$i = I_m \sin \left(\omega t - \frac{\pi}{2} \right) \text{ ---- (3)}$$

where $\frac{V_m}{L\omega} = I_m$

Inductive reactance $X_L = \omega L$

From (1) and (3) it is evident that **current lags behind** the applied voltage by $\pi/2$ in an inductive circuit.

19. Derive an expression for phase angle between the applied voltage and current in a series RLC circuit

Consider a circuit containing a resistor of resistance R, an inductor of inductance L and a capacitor of capacitance C connected across an alternating voltage source

The applied alternating voltage is

$$V = V_m \sin \omega t \dots\dots\dots (1)$$

As a result, the voltage is developed across R, L and C.

- ✓ Voltage across R (V_R) is in phase with i
- ✓ Voltage across L (V_L) Leads i by $\pi/2$
- ✓ Voltage across C (V_C) Lags i by $\pi/2$
- ✓ Let us assume circuit is purely inductive so that $V_L > V_C$ so that net voltage drop across

L-C combination is $V_L - V_C$ which is represented by a phasor $\overrightarrow{AD}$.

$$OI = I_m ; V_R = OA = I_m R ; V_L = OB = I_m X_L ; V_C = OC = I_m X_C$$

By parallelogram law, the diagonal $\overrightarrow{OE}$ gives the resultant voltage v of V_R and $(V_L - V_C)$ and its length OE is equal to V_m . Therefore,

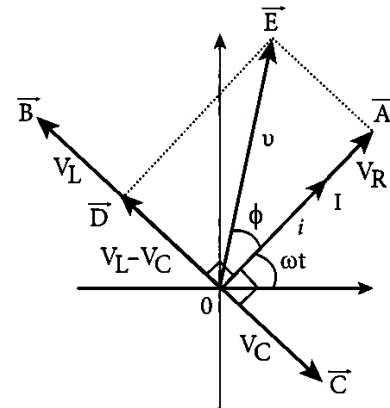
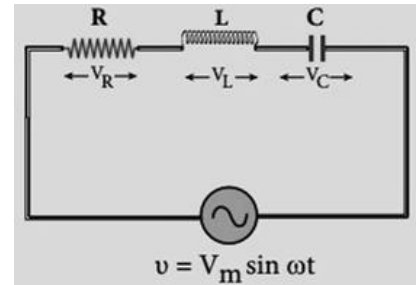
$$\begin{aligned} V_m^2 &= V_R^2 + (V_L - V_C)^2 \\ &= \sqrt{(I_m R)^2 + (I_m X_L - I_m X_C)^2} \\ &= I_m \sqrt{(R)^2 + (X_L - X_C)^2} \end{aligned}$$

$$I_m = \frac{V_m}{Z}$$

$$Z = \sqrt{(R)^2 + (X_L - X_C)^2}$$

Z - impedance of the circuit which refers to the effective opposition to the circuit current by the series RLC circuit

$$\tan \phi = \frac{V_L - V_C}{V_R} = \frac{X_L - X_C}{R}$$



20. Define inductive and capacitive reactance. Give their units.

Inductive reactance

Resistance offered by **inductor** is called inductive reactance.

Unit: ohm

$$X_L = \omega L = 2\pi\nu L \text{ where } \omega = 2\pi\nu$$

Capacitive reactance

Resistance offered by **capacitor** is called capacitive reactance.

Unit: ohm

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi\nu C} \text{ where } \omega = 2\pi\nu$$

21. Obtain an expression for average power of AC over a cycle. Discuss its special cases.

- ✓ Power of a circuit is defined as the rate of consumption of electric energy in that circuit.
- ✓ In an AC circuit, the voltage and current vary continuously with time.
- ✓ The power at an instant was calculated and then it is averaged over a complete cycle.

The alternating voltage and alternating current in the series RLC circuit at an instant are

$$V = V_m \sin\omega t \text{ \& } i = I_m \sin(\omega t + \phi)$$

ϕ – phase angle between V and i.

The instantaneous power $P = V i$ ----(1)

Sub V & i values in (1)

$$\begin{aligned} P &= V_m I_m \sin\omega t \times \sin(\omega t + \phi) \\ &= V_m I_m \sin\omega t [\sin\omega t \cos\phi + \cos\omega t \sin\phi] \text{ (since } \sin(A + B) = \sin A \cos B + \cos A \sin B) \\ &= V_m I_m [\sin^2\omega t \cos\phi - \sin\omega t \cos\omega t \sin\phi] \end{aligned}$$

- ✓ Average of $\sin^2\omega t$ over a cycle is $\frac{1}{2}$
- ✓ Average of $\sin\omega t \cos\omega t$ is 0

$$\begin{aligned} P_{av} &= V_m I_m \cos\phi \times \frac{1}{2} \\ &= \frac{V_m}{\sqrt{2}} \frac{I_m}{\sqrt{2}} \cos\phi \end{aligned}$$

$$P_{av} = V_{RMS} I_{RMS} \cos\phi \quad \left(\text{Since } \frac{V_m}{\sqrt{2}} = V_{RMS}; \frac{I_m}{\sqrt{2}} = I_{RMS} \right)$$

$V_{RMS} I_{RMS}$ - Apparent power. $\cos\phi$ - Power factor

Average power of an AC circuit is also known as the true power of the circuit.

Special cases

(i) For purely resistive circuit $\phi = 0 \rightarrow \cos\phi = 1$ $P_{av} = V_m I_m \cos\phi$

(ii) For purely inductive or capacitive circuit $\phi = \pm \frac{\pi}{2}$ $\cos\pm \frac{\pi}{2} = 0$ $P_{av} = 0$

(iii) For series RLC circuit, $\phi = \tan^{-1} \left(\frac{X_L - X_C}{R} \right)$ $P_{av} = V_m I_m \cos\phi$

(iv) For series RLC circuit at resonance, $\phi = 0$ $\cos\phi = 1$ $P_{av} = V_m I_m$

22.Explain the generation of LC oscillations in a circuit containing an inductor of inductance L and a capacitor of capacitance C

Stage (a)

Assume that the capacitor is fully charged with maximum charge Q_m at the initial stage. So that the energy stored in the capacitor is maximum and is given by $U_E = \frac{Q_m^2}{2C}$. As there is no current in the inductor, the energy stored in it is zero i.e., $U_B = 0$. Therefore, the total energy is wholly electrical.

Stage (b)

The capacitor now begins to discharge through the inductor that establishes current i in clockwise direction. This current produces a magnetic field around the inductor and the energy stored in the inductor is given by $U_B = \frac{Li^2}{2}$. As the charge in the capacitor decreases, the energy stored in it also decreases and is given by $U_E = \frac{q^2}{2C}$. Thus there is a transfer of some part of energy from the capacitor to the inductor. At that instant, the total energy is the sum of electrical and magnetic energies

Stage (c)

When the charges in the capacitor are exhausted, its energy becomes zero i.e., $U_E = 0$. The energy is fully transferred to the magnetic field of the inductor and its energy is maximum.

This maximum energy is given by $U_B = \frac{LI_m^2}{2C}$. The total energy is wholly magnetic

Stage (d)

Even though the charge in the capacitor is zero, the current will continue to flow in the same direction because the inductor will not allow it to stop immediately. The current is made to flow with decreasing magnitude by the collapsing magnetic field of the inductor. As a result of this, the capacitor begins to charge in the opposite direction. A part of the energy is transferred from the inductor back to the capacitor. The total energy is the sum of the electrical and magnetic energies

Stage (e)

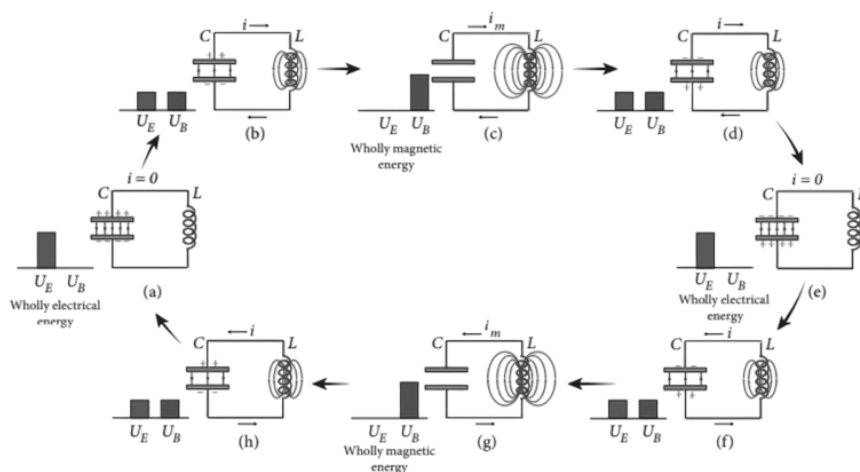
When the current in the circuit reduces to zero, the capacitor becomes fully charged in the opposite direction. The energy stored in the capacitor becomes maximum. Since the current is zero, the energy stored in the inductor is zero. The total energy is wholly electrical

Stage (f)

The state of the circuit is similar to the initial state but the difference is that the capacitor is charged in opposite direction.

The capacitor then starts to discharge through the inductor with anti-clockwise current. The

total energy is the sum of the electrical and magnetic energies



Stage (g) and (h)

Processes are repeated in opposite direction (Figure (g) and (h)). Finally, the circuit returns to the initial state (a). Thus, when the circuit goes through these stages, an alternating current flows in the circuit. As this process is repeated again and again, the electrical oscillations of definite frequency are generated. These are known as LC oscillations.

23. Prove that the total energy is conserved during LC oscillations.

- ✓ During LC oscillations in LC circuits, the energy of the system oscillates between the electric field of the capacitor and the magnetic field of the inductor .
- ✓ These two forms of energy varies with times , the total energy remains constant.
- ✓ LC oscillations takes place in accordance with law of conservation of energy

Total energy: $U = U_E + U_B$

$$U_E = \frac{q^2}{2C}, U_B = \frac{Li^2}{2}$$

$$U = \frac{q^2}{2C} + \frac{Li^2}{2}$$

Considering 3 different stages of LC oscillations and calculating the total energy of the system

Case (i) Charge in capacitor $q = Q_m$,

Current through inductor $i = 0$

$$\text{Total energy } U = \frac{Q_m^2}{2C} + 0 = \frac{Q_m^2}{2C} \dots (1)$$

Case (ii) Charge in capacitor $q = 0$,

Current through inductor $i = I_m$

$$\text{Total energy } U = 0 + \frac{1}{2} \frac{LI_m^2}{2} = \frac{LI_m^2}{2}$$

$$I_m = Q_m \omega$$

$$I_m = Q_m \times \frac{1}{\sqrt{LC}} \left(\text{where } \omega = \frac{1}{\sqrt{LC}} \right)$$

$$U = \frac{Q_m^2}{2C} \dots \dots \dots (2)$$

Case (iii) Charge in capacitor $q = q$,

Current through inductor $i = i$

$$\text{Total energy } U = \frac{q^2}{2C} + \frac{Li^2}{2}$$

$$q = Q_m \cos \omega t \quad i = -\frac{dq}{dt} = Q_m \omega \sin \omega t$$

Negative sign in current indicates charge in capacitor decreases with time

$$U = \frac{q^2}{2C} + \frac{Li^2}{2}$$

$$\begin{aligned} &= \frac{Q_m^2 \sin^2 \omega t}{2C} + \frac{LQ_m^2 \sin^2 \omega t}{2LC} \quad \left(\omega = \frac{1}{\sqrt{LC}}\right) \\ &= \frac{Q_m^2 (\cos^2 \omega t + \sin^2 \omega t)}{2C} \\ &= \frac{Q_m^2}{2C} \quad \dots\dots\dots(3) \end{aligned}$$

From (1), (2), (3) it is clear that total energy of the system remains constant i.e conserved

24. Compare the electromagnetic oscillations of LC circuit with the mechanical oscillations of block-spring system to find the expression for angular frequency of LC oscillators mathematically.

Electromagnetic oscillation	Mechanical oscillation
Charge q	Displacement x
Current $i = \frac{dq}{dt}$	Velocity $v = \frac{dx}{dt}$
Inductance “L”	Mass “m”
Reciprocal in capacitance $\frac{1}{C}$	Force constant “K”
Electrical energy $= \frac{1}{2} \left[\frac{1}{C} \right] q^2$	Potential energy $= \frac{1}{2} kx^2$
Mechanical energy $= \frac{1}{2} Li^2$	Kinetic energy $= \frac{1}{2} mv^2$
Electromagnetic energy $= \frac{1}{2} \left[\frac{1}{C} \right] q^2 + \frac{1}{2} Li^2$	Mechanical energy $= \frac{1}{2} kx^2 + \frac{1}{2} mv^2$

Angular frequency of LC oscillators

Electromagnetic energy

$$U = \frac{1}{2} \left[\frac{1}{C} \right] q^2 + \frac{1}{2} Li^2 = \text{Constant}$$

Differentiate,

$$\frac{dU}{dt} = \frac{1}{2C} \left(2q \frac{dq}{dt} \right) + \frac{1}{2} L \left(2i \frac{di}{dt} \right) = 0$$

$$\frac{dU}{dt} = \frac{1}{2C} \left(2q \frac{dq}{dt} \right) + \frac{1}{2} L \left[\frac{d}{dt} \left(\frac{dq}{dt} \right) \right] \quad \left(\text{since } i = \frac{dq}{dt} \right)$$

$$L \frac{d^2 q}{dt^2} + \frac{q}{C} = 0 \quad \text{----(1)}$$

Its solution is ,

$$q(t) = Q_m \cos(\omega t + \phi) \quad \text{----(2)}$$

Differentiate with respect to ‘t’

$$i(t) = \frac{dq}{dt} = \frac{d}{dt} [Q_m \cos(\omega t + \phi)]$$

$$i(t) = -Q_m \omega \sin(\omega t + \phi)$$

$$i(t) = -I_m \sin(\omega t + \phi) \quad (\text{since } I_m = Q_m \omega)$$

Again differentiate with respect to ‘t’

$$\frac{d^2 q}{dt^2} = -Q_m \omega^2 \cos(\omega t + \phi)$$

$$= -I_m \omega \cos(\omega t + \phi) \quad \text{---- (3)}$$

Sub (3) & (2) in (1)

$$L[-Q_m \omega^2 \cos(\omega t + \phi)] + \frac{1}{C} Q_m \cos(\omega t + \phi) = 0$$

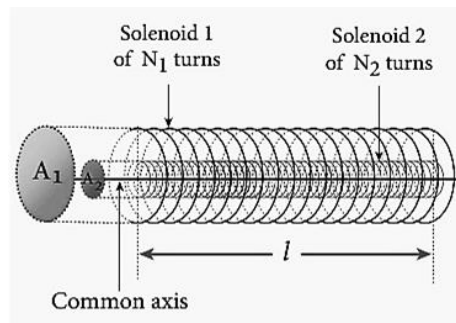
Rearranging the terms, the angular frequency of LC oscillations is given by

$$\omega = \frac{1}{\sqrt{LC}}$$

Long Answers - Book Inside

1. Derive an expression for Mutual inductance between two long co-axial solenoids

- ✓ Consider two long co-axial solenoids of same length l .
- ✓ The length of these solenoids is large when compared to their radii so that the magnetic field produced inside the solenoids is uniform and the fringing effect at the ends may be ignored.
- ✓ **A_1 and A_2** – Area of cross section of the solenoids. $A_1 > A_2$
- ✓ **n_1 & n_2** – The turn density of these solenoids
- ✓ **i_1** - current flowing through solenoid 1



Then the magnetic field produced inside it is **$B_1 = \mu_0 n_1 i_1$**

As the field lines of B_1 are passing through the area bounded by solenoid 2 the magnetic flux is linked with each turn of solenoid 2 due to solenoid 1

$$\phi_{21} = B_1 A_2$$

Sub B_1 in above equation

$$\phi_{21} = (\mu_0 n_1 i_1) A_2$$

The flux linkage of solenoid 2 with total turns N_2 is

$$N_2 \phi_{21} = (\mu_0 n_1 i_1) (n_2 l) A_2 \text{ (where } N_2 = n_2 l) \\ = (\mu_0 n_1 n_2 l A_2) i_1 \text{ ----(1)}$$

$$N_2 \phi_{21} = M_{21} i_1 \text{ ----(2)}$$

Comparing (1) and (2)

$$M_{21} i_1 = (\mu_0 n_1 n_2 l A_2) i_1$$

$$M_2 = \mu_0 n_1 n_2 l A_2 \text{ ----(3)}$$

i_2 - current flowing through solenoid 2

Then the magnetic field produced inside is

$$B_2 = \mu_0 n_2 i_2$$

As the field lines of B_2 are passing through the area bounded by solenoid 1

This magnetic field B_2 is uniform inside the solenoid 2 but outside the solenoid 2, it is almost zero. Therefore for solenoid 1, the area A_2 is the effective area over which the magnetic field B_2 is present not area A_1 .

The magnetic flux is linked with each turn of solenoid 1 due to solenoid 2

$$\phi_{12} = B_2 A_2$$

Sub B_2 in above equation

$$\phi_{12} = (\mu_0 n_2 i_2) A_2$$

The flux linkage of solenoid 2 with total turns N_2 is

$$N_1 \phi_{12} = (\mu_0 n_2 i_2) (n_1 l) A_2 \text{ where } N_1 = n_1 l \\ = (\mu_0 n_1 n_2 l A_2) i_2 \text{ ----(4)}$$

$$N_1 \Phi_{12} = M_{12} i_2 \text{----(5)}$$

Comparing (4) and (5)

$$M_{12} i_2 = (\mu_0 n_1 n_2 l A_2) i_2$$

$$M_{12} = \mu_0 n_1 n_2 l A_2$$

mutual inductance of the solenoid 2 with respect to solenoid 1 is

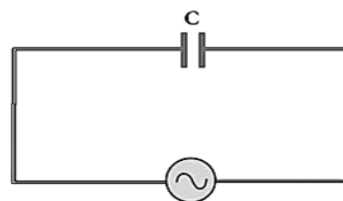
$$M_{12} = \mu_0 n_1 n_2 l A_2 \text{.....(6)}$$

From (3) & (6)

$$M_1 = M_2 = M$$

2. Find out the phase relationship between voltage and current in pure capacitive circuit.

Consider a circuit containing a capacitor of capacitance C connected across an alternating voltage source.



The instantaneous value of the alternating voltage is given by

$$V = V_m \sin \omega t \text{ ----(1)}$$

q - instantaneous charge on the capacitor.

$$C = \frac{q}{V}$$

$$q = CV$$

$$= C V_m \sin \omega t$$

$$i = \frac{dq}{dt}$$

$$= \frac{d}{dt} (C V_m \sin \omega t)$$

$$= C V_m \frac{d}{dt} (\sin \omega t)$$

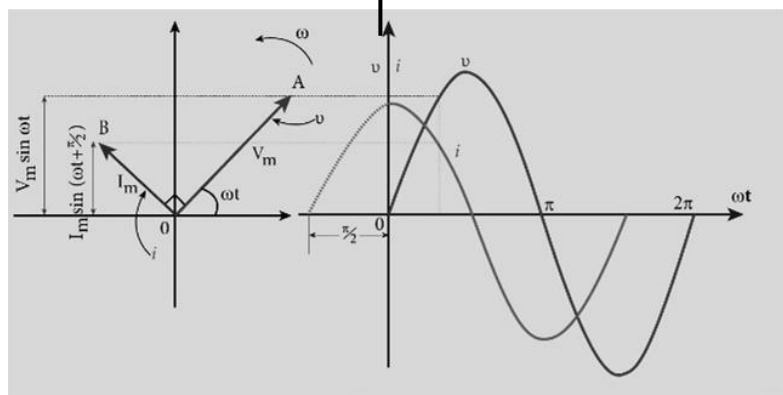
$$= \omega C V_m \cos \omega t$$

$$= \frac{V_m}{1/C\omega} \sin \left(\omega t + \frac{\pi}{2} \right)$$

$$I_m = \frac{V_m}{1/C\omega}$$

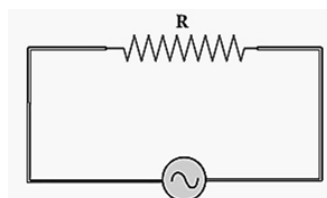
$$i = I_m \sin \left(\omega t + \frac{\pi}{2} \right) \text{----(2)}$$

From (1) & (2) it is clear that current leads the applied voltage by $\frac{\pi}{2}$ in a capacitive circuit.



3. Find out the phase relationship between voltage and current in pure resistive circuit

Consider a circuit containing a pure resistor of resistance R connected across an alternating voltage source.



The instantaneous value of the alternating voltage is given by

$$V = V_m \sin \omega t \text{ ----(1)}$$

An alternating current i flowing in the circuit due to this voltage, develops a potential drop across R and is given by

$$V_R = iR \text{ ----(2)}$$

Kirchoff's loop rule states that the algebraic sum of potential differences in a closed circuit is zero.

$$\text{For this resistive circuit: } V - V_R = 0$$

$$V_m \sin \omega t - iR = 0$$

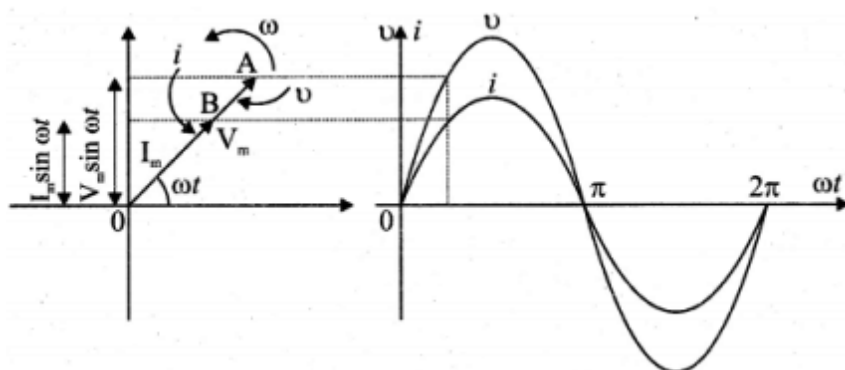
$$V_m \sin \omega t = iR$$

$$i = \frac{V_m}{R} \sin \omega t$$

$$i = I_m \sin \omega t \text{ ----(3)}$$

$$I_m = \frac{V_m}{R}$$

From (1) & (3) applied voltage and the current are in phase with each other in a resistive circuit.



Numerical Problems Solved

1. A square coil of side 30 cm with 500 turns is kept in a uniform magnetic field of 0.4 T. The plane of the coil is inclined at an angle of 30° to the field. Calculate the magnetic flux through the coil.

Given:

$$a = 30 \times 10^{-2} \text{ m,}$$

$$A = a^2 = 9 \times 10^{-2} \text{ m}^2, B = 0.4 \text{ T,}$$

$$\theta = 30^\circ$$

$$\theta = 90^\circ - 30^\circ = 60^\circ,$$

$$N = 500 \text{ turns, } \phi_B = ?$$

$$\phi_B = NBA \cos \theta$$

$$= 500 \times 0.4 \times 9 \times 10^{-2} \times \cos 60^\circ$$

$$\phi_B = 5 \times 10^2 \times 4 \times 10^{-1} \times 9 \times 10^{-2} \times \frac{1}{2}$$

$$= 10 \times 10^{-1} \times 9,$$

$$\phi_B = 9 \text{ wb}$$

Solution

2. A straight metal wire crosses a magnetic field of flux 4 mWb in a time 0.4 s. Find the magnitude of the emf induced in the wire.

$$\text{Given: } d\phi = 4 \text{ m Wb, Change in time, } dt = 0.4 \text{ s} = 4 \times 10^{-1} \text{ s } \epsilon = ?$$

Solution

$$\text{Magnitude of induced emf, } \epsilon = \frac{d\phi}{dt} = \frac{4 \times 10^{-3}}{4 \times 10^{-1}} = 10 \times 10^{-3} \text{ V}$$

$$\varepsilon = 10 \text{ mV}$$

3. The magnetic flux passing through a coil perpendicular to its plane is a function of time and is given by $\phi_B = (2t^3 + 4t^2 + 8t + 8) \text{ Wb}$. If the resistance of the coil is 5Ω , determine the induced current through the coil at a time $t = 3 \text{ second}$.

Given: $\phi_B = (2t^3 + 4t^2 + 8t + 8) \text{ wb}$, $R = 5 \Omega$, $t = 3 \text{ s}$, $i = ?$

Solution

$$\varepsilon = \frac{d\phi_B}{dt}$$

$$= \frac{d}{dt}(2t^3 + 4t^2 + 8t + 8) = (6t^2 + 8t + 8)$$

$$t = 3 \text{ s}, \varepsilon = (6(3)^2 + 8(3) + 8)$$

$$\varepsilon = 6 \times 9 + 24 + 8 = 54 + 32$$

$$= 86 \text{ V}$$

$$\therefore \text{Induced current, } i = \frac{\varepsilon}{R} = \frac{86}{5}$$

$$i = 17.2 \text{ A}$$

4. A closely wound coil of radius 0.02 m is placed perpendicular to the magnetic field. When the magnetic field is changed from 8000 T to 2000 T in 6 s , an emf of 44 V is induced. Calculate the number of turns in the coil.

Given: Radius, $r = 0.02 \text{ m}$; $r = 2 \times 10^{-2} \text{ m}$ $B_1 = 8000 \text{ T}$, $B_2 = 2000 \text{ T}$; $dt = 6 \text{ s}$

$$\varepsilon = 44 \text{ volt}; \quad \theta = 0^\circ, \quad N = ?$$

Solution

$$A = \pi r^2 = 3.14 \times (2 \times 10^{-2})^2$$

$$\varepsilon = \frac{d\phi_B}{dt}$$

$$\varepsilon = NA \frac{(B_1 - B_2)}{t} \times \cos \theta$$

$$44 = \frac{N \times 3.14 \times 4 \times 10^{-4} \times \cos 0^\circ \times (8000 - 2000)}{6}$$

$$11 = \frac{N \times 3.14 \times 10^{-4} \times 1 \times 6000}{6}$$

$$11 = N \times 3.14 \times 10^{-1}$$

$$N = \frac{110}{3.14} = \frac{110}{\frac{22}{7}}$$

$$= 5 \times 7 = 35 \text{ turns}$$

5. A rectangular coil of area 6 cm^2 having 3500 turns is kept in a uniform magnetic field of 0.4 T . Initially, the plane of the coil is perpendicular to the field and is then rotated through an angle of 180° . If the resistance of the coil is 35Ω , find the amount of charge flowing through the coil.

Given: $A = 6 \text{ cm}^2 = 6 \times 10^{-4} \text{ m}^2$, $N = 3500 = 35 \times 10^2$ turns, $B = 0.4 \text{ T}$

$$\theta_1 = 0^\circ, \quad \theta_2 = 180^\circ, \quad t = 1 \text{ s}, \quad R = 35 \Omega, \quad q = ?$$

Solution

$$\varepsilon = -\frac{d\phi_B}{dt} = \frac{NBA(\cos \theta_1 - \cos \theta_2)}{t}$$

(only considering magnitude)

$$= \frac{35 \times 10^2 \times 4 \times 10^{-1} \times 6 \times 10^{-4} \times (\cos 0^\circ - \cos 180^\circ)}{1}$$

$$= \frac{840 \times 10^{-3} \times (1+1)}{1}$$

$$= 1680 \times 10^{-3} \text{ V}$$

$$i = \frac{\varepsilon}{R} = \frac{1680 \times 10^{-3}}{35} = 48 \times 10^{-3} \text{ A}$$

$$q = i t,$$

$$q = 48 \times 10^{-3} \times 1$$

$$q = 48 \times 10^{-3} \text{ C},$$

$$\mathbf{q = 48 \text{ mC}}$$

6. An induced current of 2.5 mA flows through a single conductor of resistance 100 Ω.

Find out the rate at which the magnetic flux is cut by the conductor.

Given: Induced current, $i = 2.5 \text{ mA}$, Resistance, $R = 100 \Omega$,

Solution

$$\frac{d\phi_B}{dt} = \varepsilon, \varepsilon = i R$$

$$\frac{d\phi_B}{dt} = 2.5 \times 10^{-3} \times 100$$

$$= 250 \times 10^{-3}$$

$$\therefore \text{Rate of change of flux: } \frac{d\phi_B}{dt} =$$

$$\mathbf{250 \text{ mWb/s}}$$

7. A fan of metal blades of length 0.4 m rotates normal to a magnetic field of $4 \times 10^{-3} \text{ T}$.

If the induced emf between the centre and edge of the blade is 0.02 V, determine the rate of rotation of the blade.

Given: $l = 0.4 \text{ m}$, $B = 4 \times 10^{-3} \text{ T}$, $\varepsilon = 0.02 \text{ V} = 2 \times 10^{-2} \text{ V}$, $\omega = ?$

$$\therefore \text{Area, } A = \pi r^2 = 3.14 \times (0.4)^2$$

Solution

$$\varepsilon = NBA\omega \sin \theta \quad [N = 1, \theta = 90^\circ, \sin 90^\circ = 1]$$

$$\omega = \frac{\varepsilon}{NBA \sin \theta}$$

$$= \frac{2 \times 10^{-2}}{1 \times 4 \times 10^{-3} \times 3.14 \times (0.4)^2 \times \sin 90^\circ}$$

$$\omega = \frac{10}{2 \times 3.14 \times 0.16 \times 1}$$

$$\omega = 9.95 \text{ revolutions per second}$$

$$\mathbf{\omega = 9.95 \text{ rps}}$$

8. A bicycle wheel with metal spokes of 1 m long rotates in Earth's magnetic field. The

plane of the wheel is perpendicular to the horizontal component of Earth's field of $4 \times$

10^{-5} T . If the emf induced across the spokes is 31.4 mV, calculate the rate of revolution of the wheel.

Given: $l = 1 \text{ m}$, $B = 4 \times 10^{-5} \text{ T}$, Area, $A = \pi r^2 = 3.14 \times (1)^2 = 3.14 \text{ m}^2$

$$\text{emf, } \varepsilon = 31.4 \text{ mV} = 31.4 \times 10^{-3} \text{ V}, \varepsilon = 3.14 \times 10^{-2} \text{ V}, \omega = ?$$

Solution

$$\varepsilon = NBA\omega \sin \theta$$

$$\omega = \frac{\varepsilon}{NBA \sin \theta}; [N = 1, \theta = 90^\circ \sin 90^\circ = 1]$$

$$\omega = \frac{3.14 \times 10^{-2}}{1 \times 4 \times 10^{-5} \times 3.14 \times \sin 90^\circ}$$

$$\omega = \frac{1000}{4 \times 1} = 250 \text{ resolutions/s}$$

$$\omega = 250 \text{ rps}$$

9. Determine the self-inductance of 4000 turn air-core solenoid of length 2m and diameter 0.04 m.

Given: $N = 4000$ turns, $l = 2$ m, diameter $d = 0.04$ m, $r = 0.02$ m ; $r = 2 \times 10^{-2}$

$$L = ? , A = \pi r^2$$

Solution: $L = \mu_0 n^2 A l, \quad n = \frac{N}{l}$

$$\begin{aligned} L &= \frac{\mu_0 N^2 A}{l} \\ &= \frac{4\pi \times 10^{-7} \times (4000)^2 \times 3.14 \times (2 \times 10^{-2})^2}{2} \\ &= 2 \times 3.14 \times 10^{-7} \times 16 \times 10^6 \times 3.14 \times 4 \\ &\quad \times 10^{-4} \end{aligned}$$

$$\begin{aligned} &= 3.14 \times 3.14 \times 128 \times 10^{-5} \\ &= 1262.02 \times 10^{-5} \text{ H} \\ &= 12.62 \times 10^{-3} \text{ H} \end{aligned}$$

$$L = 12.62 \text{ mH}$$

10. A coil of 200 turns carries a current of 4 A. If the magnetic flux through the coil is 6×10^{-5} Wb, find the magnetic energy stored in the medium surrounding the coil.

Given: $N = 200 = 2 \times 10^2$ turns, $I = 4$ A,

Solution

$$U_B = \frac{1}{2} LI^2;$$

$$LI = N\phi_B, L = \frac{N\phi_B}{I}$$

$$U_B = \frac{1}{2} \times \frac{N\phi_B}{I} \times I^2$$

$$= \frac{1}{2} \times N\phi_B \times I$$

$$U_B = \frac{1}{2} \times 2 \times 10^2 \times 6 \times 10^{-5} \times 4$$

$$U_B = 24 \times 10^{-3} \text{ J}$$

$$\therefore U_B = 0.024 \text{ J}$$

11. A 50 cm long solenoid has 400 turns per cm. The diameter of the solenoid is 0.04 m.

Find the magnetic flux of a turn when it carries a current of 1 A.

Given: $l = 50 \text{ cm} = 5 \times 10^{-1} \text{ m}$, $n = 400 \text{ turns/cm} = \frac{400}{10^{-2} \text{ m}} = 4 \times 10^4 \text{ turns}$

diameter $d = 0.04 \text{ m}$, radius, $r = 0.02 \text{ m}$, $r = 2 \times 10^{-2} \text{ m}$ $A = \pi r^2 = 3.14 \times (2 \times 10^{-2})^2 \text{ m}^2$, $A = 12.56 \times 10^{-4} \text{ m}^2$ $\phi_B = ?$ $I = 1 \text{ A}$

Solution

$$\phi_B = LI, \quad L = \mu_0 n^2 A l$$

$$\phi_B = \mu_0 n^2 A l \times I$$

$$\begin{aligned} &= 12.56 \times 10^{-12} \times 16 \times 10^8 \times 12.56 \\ &\quad \times 5 \end{aligned}$$

$$= 12.56 \times 12.56 \times 80 \times 10^{-4}$$

$$= 1.262 \times 10^4 \times 10^{-4} \text{ Wb}$$

$$\phi_B = 1.262 \text{ Wb}$$

Magnetic flux linked with each turn

$$\frac{\Phi_B}{N} = \frac{1.262}{20000} = 0.631 \times 10^{-4} \text{ Wb}$$

12. A coil of 200 turns carries a current of 0.4 A. If the magnetic flux of 4 mWb is linked with the coil, find the inductance of the coil.

Given: $N = 200$ turns, $I = 0.4 \text{ A} = 4 \times 10^{-1}$, $\Phi_B = 4 \text{ mWb} = 4 \times 10^{-3} \text{ Wb}$, $L = ?$

Solution

$$N\Phi_B = LI, \quad L = \frac{N\Phi_B}{I} = \frac{200 \times 4 \times 10^{-3}}{4 \times 10^{-1}}$$

$$L = 2 \text{ H}$$

13. Two air core solenoids have the same length of 80 cm and same cross-sectional area 5 cm^2 . Find the mutual inductance between them if the number of turns in the first coil is 1200 turns and that in the second coil is 400 turns.

Given: $l = 80 \text{ cm} = 8 \times 10^{-1}$, $A = 5 \text{ cm}^2$, $A = 5 \times 10^{-4} \text{ m}^2$, $N_1 = 1200 = 12 \times 10^2$, $N_2 = 400 = 4 \times 10^2$

Solution

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

$$M = \mu_0 n_1 n_2 A l, \quad n_1 = \frac{N_1}{l}; \quad n_2 = \frac{N_2}{l}$$

$$M = \frac{4\pi \times 10^{-7} \times 12 \times 10^2 \times 4 \times 10^2 \times 5 \times 10^{-4}}{8 \times 10^{-1}}$$

$$= 4 \times 3.14 \times 30 \times 10^{-6}$$

$$= 12.56 \times 3 \times 10^{-5}$$

$$= 37.68 \times 10^{-5} \text{ H}$$

$$= 0.3768 \times 10^{-3} \text{ H}$$

$$\therefore M = 0.38 \text{ m H}$$

14. A long solenoid having 400 turns per cm carries a current 2A. A 100 turn coil of cross-sectional area 4 cm^2 is placed co-axially inside the solenoid so that the coil is in the field produced by the solenoid. Find the emf induced in the coil if the current through the solenoid reverses its direction in 0.04 sec.

Given: $N_1 = \frac{400}{10^{-2}} = 400 \times 10^2 = 4 \times 10^4$, $N_2 = 100 = 10^2$, $A = 4 \text{ cm}^2 = 4 \times 10^{-4} \text{ m}^2$

$I = 2 \text{ A}$, $t = 0.04 \text{ s} = 4 \times 10^{-2} \text{ s}$, $\varepsilon = ?$

Solution

$$\varepsilon = -M \frac{dI}{dt} \Rightarrow (1)$$

$$M = \mu_0 n_1 n_2 A l = \frac{\mu_0 N_1 N_2 A}{l}$$

$$n_1 = \frac{N_1}{l}; \quad n_2 = \frac{N_2}{l}$$

$$M = \frac{4\pi \times 10^{-7} \times 4 \times 10^4 \times 10^2 \times 4 \times 10^{-4}}{1}$$

$$= 4 \times 3.14 \times 16 \times 10^{-5}$$

$$= 2 \times 10^{-3} \text{ H}$$

$$\therefore M = 2 \text{ mH}$$

$$\varepsilon = M \frac{dI}{dt}$$

$$= 2 \times 10^{-3} \times \frac{4}{4 \times 10^{-2}} = 2 \times 10^{-1} \text{ V}$$

$$\varepsilon = 0.2 \text{ V}$$

15. A 200 turn coil of radius 2 cm is placed co-axially within a long solenoid of 3 cm radius. If the turn density of the solenoid is 90 turns per cm, then calculate mutual inductance of the coil.

Given: $N_2 = 200$, $r = 2 \times 10^{-2}$ m, $N_1 = 90$ turns/cm = $\frac{90}{10^{-2}} = 90 \times 10^2$

$$A = \pi r^2 = 3.14 \times (2 \times 10^{-2})^2, \quad M = ?$$

Solution

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

$$= \frac{4\pi \times 10^{-7} \times 9 \times 10^3 \times 2 \times 10^2 \times 3.14 \times (2 \times 10^{-2})^2}{1}$$

$$= 4 \times 3.14 \times 18 \times 3.14 \times 4 \times 10^{-4}$$

$$\times 10^{-2}$$

$$= 12.56 \times 18 \times 12.56 \times 10^{-6}$$

$$= 2.84 \times 10^{-3} \text{ H}$$

$$\therefore M = 2.84 \text{ mH}$$

16. The solenoids S_1 and S_2 are wound on an iron-core of relative permeability 900. The area of their cross-section and their length are the same and are 4 cm^2 and 0.04 m respectively. If the number of turns in S_1 is 200 and that in S_2 is 800, calculate the mutual inductance between the coils. The current in solenoid 1 is increased from 2 A to 8 A in 0.04 second. Calculate the induced emf in solenoid 2.

Given: $\mu_r = 900 = 9 \times 10^2$, $l = 0.04 \text{ m}$, $l = 4 \times 10^{-2} \text{ m}$, $A = 4 \text{ cm}^2 = 4 \times 10^{-4} \text{ m}^2$,
 $N_1 = 200 = 2 \times 10^2$ turns, $N_2 = 800 = 8 \times 10^2$ turns, $I_1 = 2 \text{ A}$, $I_2 = 8 \text{ A}$, $dI = I_2 - I_1 =$
 $8 - 2 = 6 \text{ A}$, $t = 0.04 \text{ s}$; $t = 4 \times 10^{-2} \text{ s}$ $\varepsilon_2 = ?$

Solution

The induced emf in solenoid 2 is

$$\varepsilon_2 = -M \frac{dI}{dt};$$

$$M = \frac{\mu_0 \mu_r N_1 N_2 A}{l}$$

$$= \frac{4\pi \times 10^{-7} \times 2 \times 10^2 \times 8 \times 10^2 \times 4 \times 10^{-4} \times 9 \times 10^2}{4 \times 10^{-2}}$$

$$= 4 \times 3.14 \times 16 \times 9 \times 10^{-3}$$

$$= 12.56 \times 144 \times 10^{-3}$$

$$= 1.81 \times 10^{-3} \times 10^3$$

$$M = 1.81 \text{ H}$$

$$\varepsilon_2 = -M \frac{dI}{dt} = -1.81 \times \frac{6}{4 \times 10^{-2}}$$

$$\varepsilon_2 = -2.715 \times 10^2 \text{ V}$$

$$\varepsilon_2 = -271.5 \text{ V}$$

$$\therefore \text{Magnitude of emf, } \varepsilon = -271.5 \text{ V}$$

17. A step-down transformer connected to main supply of 220 V is made to operate $11 \text{ V}, 88 \text{ W}$ lamp. Calculate (i) Transformation ratio and (ii) Current in the primary.

Given: $V_p = 220 \text{ V}$, $V_s = 11 \text{ V}$; Output power = $V_s I_s = 88 \text{ W}$, $K = ?$, $I_p = ?$

Solution

$$(i) \text{ Transformer Ratio (k)} = \frac{V_s}{V_p} = \frac{11}{220} = \frac{1}{20}$$

$$k = \frac{1}{20}$$

$$(ii) V_s I_s = 88, 11 \times I_s = 88 \\ = 0.4 \text{ A}$$

$$I_s = 8 \text{ A},$$

$$\frac{I_p}{I_s} = \frac{V_s}{V_p}; I_p = \frac{V_s}{V_p} \times I_s$$

$$I_p = \frac{11}{220} \times 8 = 0.4 \text{ A}$$

18. A 200V/120V step-down transformer of 90% efficiency is connected to an induction stove of resistance 40Ω . Find the current drawn by the primary of the transformer.

Given: $V_p = 200 \text{ V}$, $V_s = 120 \text{ V}$, $\eta = 90\% = \frac{90}{100}$, $R_s = 40 \Omega$, $I_p = ?$

Solution

$$V_s = I_s R_s$$

$$I_s = \frac{V_s}{R_s} = \frac{120}{40} = 3 \text{ A}; I_s = 3 \text{ A}$$

$$\eta = \frac{V_s I_s}{V_p I_p}; \frac{90}{100} = \frac{120 \times 3}{200 \times I_p}$$

$$I_p = 2 \text{ A}$$

19. The 300 turn primary of a transformer has resistance 0.82Ω and the resistance of its secondary of 1200 turns is 6.2Ω . Find the voltage across the primary if the power output from the secondary at 1600V is 32 kW. Calculate the power losses in both coils when the transformer efficiency is 80%.

Given: $N_p = 300$, $R_p = 0.82 \Omega$, $N_s = 1200$, $R_s = 6.2 \Omega$, $V_p = ?$, $V_s = 1600 \text{ V}$

$$\text{Output power} = V_s I_s = 32 \text{ kW} = 32 \times 10^3 \text{ W}, \eta = 80\%, \eta = \frac{80}{100}$$

$$\text{Power losses: } I_p^2 R_p = ? , I_s^2 R_s = ?$$

Solution

$$\frac{V_p}{V_s} = \frac{N_p}{N_s}$$

$$V_p = \frac{N_p}{N_s} \times V_s = \frac{300}{1200} \times 1600;$$

$$V_p = 400 \text{ V}$$

(ii) Output power,

$$V_s I_s = 32 \times 10^3 \text{ W}$$

$$I_s = \frac{32 \times 10^3}{16 \times 10^2} = 20 \text{ A}$$

$$I_s = 20 \text{ A}$$

$$\eta = \frac{V_s I_s}{V_p I_p} = \frac{80}{100} = \frac{1600 \times 20}{400 \times I_p}$$

$$I_p = 100 \text{ A}$$

$$\therefore \text{Power loss in primary coil} = I_p^2 R_p$$

$$\therefore I_p^2 R_p = (100)^2 \times 0.82 = 8200 \text{ W} \\ = 8.2 \times 10^3 \text{ W}$$

$$I_p^2 R_p = 8.2 \text{ kW}$$

$$\text{Power loss in secondary coil,} = I_s^2 R_s$$

$$I_s^2 R_s = (20)^2 \times 6.2$$

$$= 4 \times 10^2 \times 6.2$$

$$= 24.8 \times 10^2$$

$$= 2.48 \times 10^3 \text{ W}$$

$$I_s^2 R_s = 2.48 \text{ kW}$$

20. Calculate the instantaneous value at 60° , average value and RMS value of an alternating current whose peak value is 20 A.

Given:

$$\theta = 60^\circ, I_m = 20 \text{ A}, I_{av} = ?, I_{rms} = ? \quad i = ?$$

Solution:

(i) Instantaneous current,

$$i = I_m \sin \omega t$$

$$\theta = \omega t, \quad i = 20 \sin 60^\circ = 20 \times \frac{\sqrt{3}}{2}$$

$$i = 10 \times 1.732 = 17.32 \text{ A}$$

$$\mathbf{i = 17.32 \text{ A}}$$

(ii) $I_{average}$

$$I_{av} = \frac{2 I_m}{\pi} = \frac{2 \times 20}{3.14}$$

$$= \frac{40}{3.14} = 1.275 \times 10^1$$

$$\mathbf{I_{av} = 12.75 \text{ A}}$$

(iii) I_{rms}

$$I_{rms} = \frac{I_m}{\sqrt{2}} = 0.707 I_m = 0.707 \times 20 \therefore \mathbf{I_{rms} = 14.14 \text{ A}}$$

UNIT 5 – ELECTROMAGNETIC WAVES

Important Questions

Two Marks - Book Back	
1.What is displacement current? 2.Write down the integral form of modified Ampere’s circuital law 3.Write a note on Gauss law in magnetism 4.Give two uses each of (i) IR radiation (ii)Microwaves (iii) UV radiation 5.What is Fraunhofer lines? How are they useful in the identification of elements present in the sun 6.Write a note on Ampere-Maxwell law	
Three Marks - Book Back	
1.Write short notes in a) microwave b) X-ray c)radio waves d)Visible light spectrum 2.Write down the importance of Maxwell’s correction 3.Write down properties of electromagnetic waves	
Five marks - Book Back	
1.Write down Maxwell equation in integral form. 2.Discuss Hertz Experiment	3.Emission spectra & their types 4. Absorption spectra & their types

Important Formulae

1. Faraday’s Law of electromagnetic induction:

Change in magnetic field produces an electric field: $\oint \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \Phi_B = -\frac{\partial}{\partial t} \oint \vec{B} \cdot d\vec{A}$

Change in electric field produces an magnetic field: $\oint \vec{B} \cdot d\vec{l} = -\frac{\partial}{\partial t} \Phi_E = -\frac{\partial}{\partial t} \oint \vec{E} \cdot d\vec{A}$

2. Ampere’s Law in equation form $\oint \vec{B} \cdot d\vec{l} = \mu_0 I(t)$

3. Ampere’s circuital Law, $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_c$

4. Maxwell modified Ampere’s Law $\oint \vec{B} \cdot d\vec{l} = \mu_0 I = \mu_0 (I_c + I_d)$

5.Maxwell’s equations in integral form

(i) $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}$ (Gauss’s Law) (ii) $\oint \vec{B} \cdot d\vec{A} = 0$ (Gauss’s Law For Magnetism)

(iii) $\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \Phi_B$ (Faraday’s Law) (iv) $\oint \vec{B} \cdot d\vec{l} = \mu_0 I_{\text{enclosed}} + \mu_0 \epsilon_0 \frac{d}{dt} \oint \vec{E} \cdot d\vec{A}$

(Ampere – Maxwell’s Law)

5. Velocity of light, $C = \frac{1}{\sqrt{\epsilon_0 \mu_0}} = 3 \times 10^8 \text{ ms}^{-1}$

6. Refractive index of the medium, $\mu = \frac{c}{v} = \frac{\sqrt{\epsilon\mu}}{\sqrt{\epsilon_0\mu_0}} \Rightarrow \mu = \sqrt{\epsilon_r\mu_r}$

7. Propagation of Electromagnetic wave equation in electric and magnetic field,

$$E_y = E_0 \sin(kz - \omega t), \quad B_x = B_0 \sin(kz - \omega t),$$

8. Speed of Electromagnetic Wave in a medium, $V = \frac{E_0}{B_0} < c$

Text Book One Marks Solved

1. The dimension of $\frac{1}{\mu_0\epsilon_0}$ is

- (a) $[L T^{-1}]$ (b) $[L^2 T^{-2}]$ (c) $[L^{-1} T]$ (d) $[L^{-2} T^2]$

Hint: $c^2 = \frac{1}{\mu_0\epsilon_0} = [LT^{-1}]^2$

Answer: (b) $[L^2 T^{-2}]$

2. If the amplitude of the magnetic field is $3 \times 10^{-6} T$, then amplitude of the electric field for a electromagnetic waves is

- (a) $100 V m^{-1}$ (b) $300 V m^{-1}$ (c) $600 V m^{-1}$ (d) $900 V m^{-1}$

Hint: $v = \frac{E}{B}, E = B \times v = 3 \times 10^{-6} \times 3 \times 10^8 = 900$

Answer: (d) $900 Vm^{-1}$

3. Which of the following electromagnetic radiation is used for viewing objects through fog

- (a) microwave (b) gamma rays (c) X- rays (d) infrared

Answer: (d) infrared

4. Which of the following are false for electromagnetic waves

- (a) transverse (b) mechanical waves
(c) longitudinal (d) produced by accelerating charges

Answer: (c) longitudinal

5. Consider an oscillator which has a charged particle and oscillates about its mean position with a frequency of 300 MHz. The wavelength of electromagnetic waves produced by this oscillator is

- (a) 1 m (b) 10 m (c) 100 m (d) 1000 m

Hint: $v = c\lambda,$

$$\lambda = \frac{v}{c} = \frac{300 \times 10^6}{3 \times 10^8} = 1 \text{ m}$$

Answer: (a) 1 m

6. The electric and the magnetic field, associated with an electromagnetic wave, propagating along X axis can be represented by

(a) $\vec{E} = E_0\hat{j}$ and $\vec{B} = B_0\hat{k}$

(b) $\vec{E} = E_0\hat{k}$ and $\vec{B} = B_0\hat{j}$

(c) $\vec{E} = E_0\hat{i}$ and $\vec{B} = B_0\hat{j}$

(d) $\vec{E} = E_0\hat{j}$ and $\vec{B} = B_0\hat{i}$

Hint: $E = E\hat{j}$ and $B = B\hat{k}$

$$E \times B = (\hat{j} \times \hat{k})EB = EB\hat{i} \text{ (along x axis)}$$

Answer: (b) $\vec{E} = E_0\hat{k}$ and $\vec{B} = B_0\hat{j}$

7. In an electromagnetic wave in free space the rms value of the electric field is 3 V m^{-1} . The peak value of the magnetic field is

(a) $1.414 \times 10^{-8} \text{ T}$

(b) $1.0 \times 10^{-8} \text{ T}$

(c) $2.828 \times 10^{-8} \text{ T}$

(d) $2.0 \times 10^{-8} \text{ T}$

Hint: $\frac{E_{\text{rms}}}{B_{\text{rms}}} = c \Rightarrow B_{\text{rms}} = \frac{B_0}{\sqrt{2}} = \frac{E_{\text{rms}}}{c}$

Answer: (a) $1.414 \times 10^{-8} \text{ T}$

8. An e.m wave is propagating with a velocity $\vec{v} = v\hat{i}$. The instantaneous oscillating electric field of this e.m wave is along +y axis, then the direction of oscillating magnetic field of the e.m wave will be along:

(a) -y direction

(b) -x direction

(c) +z direction

(d) -z direction

Answer: (c) +z direction

9. If the magnetic monopole exists, then which of the Maxwell's equation to be modified?

(a) $\oint \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}$

(b) $\oint_S \vec{B} \cdot d\vec{A} = 0$

(c) $\oint \vec{B} \cdot d\vec{A} = \mu_0 I_{\text{enclosed}} + \mu_0 \epsilon_0 \frac{d}{dt} \int \vec{E} \cdot d\vec{A}$

(d) $\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \phi_B$

Hint: There is no monopole, so there will be no magnetic flux in that case $\text{Flux} = 0$

Answer: (b) $\oint_S \vec{B} \cdot d\vec{A} = 0$

10. Fraunhofer lines are an example of

(a) line emission

(b) line absorption

(c) band emission

(d) band absorption

Answer: (b) line absorption

11. Which of the following is an electromagnetic wave?

(a) α - rays

(b) β - rays

(c) γ - rays

(d) all of them

Hint: α - rays - helium nucleus, β - rays - electron, γ - rays - electromagnetic waves

Answer: (c) γ - rays

12. Which one of them is used to produce a propagating electromagnetic wave?

(a) an accelerating charge

(b) a charge moving at constant velocity

(c) a stationary charge

(d) an uncharged particle

Answer:(a) an accelerating charge

13. Let $E = E_0 \sin[10^6 x - \omega t]$ be the electric field of plane electromagnetic wave, the value of ω is

- (a) $0.3 \times 10^{-14} \text{ rad s}^{-1}$ (b) $3 \times 10^{-14} \text{ rad s}^{-1}$ (c) $0.3 \times 10^{14} \text{ rad s}^{-1}$ (d) $3 \times 10^{14} \text{ rad s}^{-1}$

Hint: $E = E_0 \sin(kz - \omega t)$, $E = E_0 \sin[10^6 x - \omega t]$ compare with above equation

$$k = 10^6 \quad \omega = k \times c = 10^6 \times 3 \times 10^8$$

Answer:(d) $3 \times 10^{14} \text{ rad s}^{-1}$

14. Which of the following is NOT true for electromagnetic waves?

- (a) it transports energy
(b) it transports momentum
(c) it transports angular momentum
(d) in vacuum, it travels with different speeds which depend on their frequency

Answer: (d) in vacuum, it travels with different speeds which depend on their frequency

15. The electric and magnetic fields of an electromagnetic wave are

- (a) in phase and perpendicular to each other
(b) out of phase and not perpendicular to each other
(c) in phase and not perpendicular to each other
(d) out of phase and perpendicular to each other

Answer: (a) in phase and perpendicular to each other

Creative One Marks Solved

1. In which of the following sequences are the electromagnetic radiations in decreasing order of wavelength

- a) Infrared, radio, X- rays, visible
c) Radio, visible, infrared, X-rays
- b) Radio, infrared, visible, X- rays**
d) X- rays, visible, infrared, radio

2. Which of the following radiations has the longest wavelength?

- a) Radio waves** b) IR radiation c) X-ray d) Visible light

3. The frequencies of X-rays, γ -rays and UV rays are respectively a, b and c. then

- a) $a < b, b < c$ **b) $a < b, b > c$** c) $a > b, b > c$ d) $a > b, b < c$

4. Frequency of a wave is $6 \times 10^{15} \text{ Hz}$. The wave is

- a) Radio wave b) Micro wave c) X- ray **d) UV rays**

5. Dimensions of $\frac{1}{\epsilon_0 \mu_0}$ where symbols have their usual meaning are

- a) $[L^{-2}T^2]$ **b) $[L^2T^{-2}]$** c) $[LT^{-1}]$ d) $[L^{-1}T]$

6. If $\lambda_v, \lambda_x, \lambda_m$, represent the wavelength of visible light, X- rays and microwaves, respectively, then

a) $\lambda_m > \lambda_v > \lambda_x$

b) $\lambda_m > \lambda_x > \lambda_v$

c) $\lambda_v > \lambda_m > \lambda_x$

d) $\lambda_v > \lambda_x > \lambda_m$

7. If ϵ_0 and μ_0 are the electric permittivity and permeability of free space, ϵ and μ are the corresponding quantities in a medium, then the index of refraction of the medium is

a) $\sqrt{\frac{\epsilon_0 \mu}{\epsilon \mu_0}}$

b) $\sqrt{\frac{\epsilon}{\epsilon_0}}$

c) $\sqrt{\frac{\epsilon_0 \mu_0}{\epsilon \mu}}$

d) $\sqrt{\frac{\epsilon \mu}{\epsilon_0 \mu_0}}$

Solution:

$$\text{Index of refraction} = \frac{c}{c_m} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \times \frac{\sqrt{\epsilon \mu}}{1} = \sqrt{\frac{\epsilon \mu}{\epsilon_0 \mu_0}}$$

8. In an electromagnetic wave the phase difference between electric field $\vec{E}$ and magnetic field $\vec{B}$ is

a) $\frac{\pi}{4}$

b) $\frac{\pi}{2}$

c) π

d) zero

9. The dimension of $\frac{1}{2} \epsilon_0 E^2$ is

a) $ML^{-1}T^{-2}$

b) ML^2T^{-2}

c) ML^2T^{-1}

d) ML^{-1}

10. In an electromagnetic wave propagating in free space is described by $E = E_0 \sin(Kx + \omega t)$, then

a) $E_0 \omega = B_0 K$

b) $E_0 B_0 = \omega / K$

c) $E_0 K = B_0 \omega$

d) $E_0 \omega = K / B_0$

Solution:

$$\frac{E_0}{B_0} = c = \frac{\omega}{K} \therefore E_0 K = B_0 \omega$$

11. In an electron magnetic wave the electric and magnetic fields are 100 V m^{-1} and 0.265 Am^{-1} . the maximum energy flow is

a) 46.7

b) 26.5

c) 53.5

d) 76.5

Solution:

$$\text{Max energy, } S = E_0 \times B_0 = 100 \times 0.265 = 26.5$$

12. If a charge is oscillated by an electric field 18 V m^{-1} , then the magnitude of oscillating magnetic field is

a) $12 \times 10^{-8} \text{ T}$

b) $6 \times 10^{-8} \text{ T}$

c) $3 \times 10^{-8} \text{ T}$

d) $18 \times 10^{-8} \text{ T}$

13. The condition under which a microwave oven heats up a food item in which frequency of the microves

- a) must be less than resonant frequency of water molecules
 b) must be greater than resonant frequency of water molecules.
c) must be equal to resonant frequency of water molecules.
 d) None of these

14. If the wavelength of radio wave emitted by hydrogen is 21 cm then the energy of the emitted wave is

- a) 10^{-12} **b) 10^{-24}** c) 10^{-18} d) 10^{-36}

Solution:

$$E = \frac{hc}{\lambda} = \frac{6.6 \times 10^{-34} \times 3 \times 10^8}{21 \times 10^{-2}} = 10^{-24} \text{ J}$$

15. Which rays are used to analyze structure of atoms.

- a) IR b) gamma c) X- rays **d) UV**

16. To study about nuclear structure which rays are used.

- a) UV b) IR **c) gamma** d) visible

17. The radiation which is used in physiotherapy are

- a) visible **b) IR** c) UV d) Micro wave

18. Which spectrum is produced by an incandescent solid at high temperature?

- a) A pure spectrum **b) A continuous spectrum**
 c) A line spectrum d) An absorption spectrum

19. The momentum delivered to the surface by an electromagnetic wave is

- a) $\frac{U}{c}$ b) $\frac{U}{2c}$ **c) $\frac{2U}{c}$** d) Uc

20. The waves which have longest wavelength is

- a) UV b) IR c) Micro **d) Radio**

21. The dimension of $\frac{1}{\mu\epsilon}$ is

- a) $[L^{-2}T^{-2}]$ b) $[LT^{-1}]$ c) $[L^2T^2]$ **d) $[L^2T^{-2}]$**

Solution:

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$$v^2 = \frac{1}{\mu\epsilon} = [LT^{-1}]^2 = [L^2T^{-2}]$$

22. The ratio of speed of gamma rays to that of ultraviolet rays

- a) 2 b) $\sqrt{2}$ c) 0.1 **d) 1**

23. The charging current for a capacitor is 0.25A. The displacement current across its plates

- a) 10 A b) 4 A **c) 0.25 A** d) 0.5 A

Solution:

Displacement current remains the same as charging current and is equal to 0.25A

24. The existence of electromagnetic waves was confirmed experimentally by

- a) Hertz** b) Maxwell c) Huygens d) Planck

25. Which one of the following is not an electromagnetic wave

- a) X – rays b) γ – rays c) U – V rays **d) β – rays**

26. Atomic spectrum should be

- a) Pure line spectrum** b) emission band spectrum
c) Absorption line spectrum d) absorption band spectrum

27. Electric filament lamp gives rise to

- a) Line spectrum **b) continuous spectrum**
c) band spectrum d) line absorption spectrum

28. The potential difference between the plates of a parallel plate capacitor is changing at the rate of 10^6 Vs^{-1} . If the capacitance is $2\mu\text{F}$. The displacement current in the dielectric of the capacitor

- (a) 4 A (b) 3 A **(c) 2A** (d) 1 A

29. In an electromagnetic wave

- a) Power is equally transferred along the electric and magnetic fields

b) Power is transmitted in a direction perpendicular to both the fields

- c) Power is transmitted along electric field
d) Power is transmitted along magnetic field

30. Electromagnetic waves are

- a) Transverse** b) longitudinal
c) may be longitudinal or transverse d) neither longitudinal nor transverse

31. The energy density of an electromagnetic waves of intensity 0.02 Wm^{-2} is

- (a) $6.67 \times 10^{-11} \text{ Jm}^{-3}$** (b) $6 \times 10^6 \text{ Jm}^{-3}$ (c) $1.5 \times 10^{10} \text{ Jm}^{-3}$ (d) none of these

Solution: $u_E = \frac{1}{2} \epsilon_0 E^2$

32. The constituent radiation of the electromagnetic spectrum is used for aircraft navigation

- (a) X -Rays **(b) Microwaves** (c) X – rays (d) visible light

33. A charged particle oscillates about its mean equilibrium position with a frequency of 10^9 Hz . The frequency of the electromagnetic waves produced by the oscillator

- (a) 10^{18} Hz (b) 10^{20} Hz **(c) 10^9 Hz** (d) 10^{11} Hz

Solution:

The frequency of an electromagnetic wave produced by the oscillator is the same as that of a charged particle oscillating about its mean position

34. One requires 11eV of energy to dissociate a carbon monoxide molecule into carbon and oxygen atoms. The minimum frequency of the appropriate electromagnetic radiation to achieve the dissociation lies in

- (a) visible region. (b) infrared region.

- (c) **ultraviolet region** (d) microwave region.

Solution: $E = h\nu$ 2.65×10^{15} Hz This frequency radiation belongs to ultraviolet region.

35. Electromagnetic waves travelling in a medium which has relative permeability 1.3 and relative permittivity 2.14, speed of electromagnetic waves in this medium will be

- (a) 3.6×10^8 m/s (b) **1.8×10^8 m/s**
(c) 1.8×10^6 m/s (d) 13.6×10^6 m/s

36. An electromagnetic wave going through vacuum is described by $E = E_0 \sin \omega t$ Which of the following is independent of the wavelength?

- (a) ω (b) **k/ω** (c) $k\omega$ (d) k

37. Speed of electromagnetic wave is the same

- (a) for all wavelengths (b) in all media
(c) **for all intensities** (d) for all frequencies

38. The electromagnetic waves do not transport

- (a) energy (b) **charge** (c) momentum (d) information

39. The frequency of an electromagnetic wave in free space is 3MHz. When it passes through a medium of relative permeability $\epsilon_r = 4$, then its frequency

- (a) becomes half (b) **becomes doubled**
(c) remains same (d) become $\sqrt{2}$ time

40. The unit of $\mu_0 c$ is same as that of

- (a) current (b) **resistance** (c) electric charge (d) velocity

Short Answers - Book Back

1. What is displacement current?

It can be defined as the current which comes into play in the region in which the **electric field and the electric flux are changing with time.**

2. What are electromagnetic waves?

Electromagnetic waves are non-mechanical waves which move with speed equals to the speed of light (in vacuum).

3. Write down the integral form of modified Ampere's circuital law

$$\oint_l \vec{B} \cdot d\vec{l} = \mu_0 i_c + \mu_0 \epsilon_0 \frac{d}{dt} \oint_s \vec{E} \cdot d\vec{A}$$

This law relates the magnetic field around any closed path to the conduction current and displacement current through that path

4. Write a note on Gauss law in magnetism

- ✓ The surface integral of magnetic field over a closed surface is zero. $\oint_s \vec{B} \cdot d\vec{A} = 0$
- ✓ This equation implies that the magnetic lines of force form a continuous closed path. In other words, it means that no isolated magnetic monopole exists.

5. Give two uses each of (i) IR radiation (ii) Microwaves (iii) UV radiation

(i) IR radiation

- ✓ To produce dehydrated fruits, in green houses to keep the plants warm, heat therapy for muscular pain or sprain,
- ✓ Used in night vision or infrared photography

(ii) Microwaves

- ✓ Used in radar system for aircraft navigation, speed of the vehicle
- ✓ Microwave oven for cooking

(iii) UV radiation

- ✓ Used to destroy bacteria, sterilizing the surgical instruments,
- ✓ To detect the invisible writing

6. What is Fraunhofer lines? How are they useful in the identification of elements present in the sun?

When the **spectrum obtained from the Sun** is examined, it consists of large number of **dark lines** (line absorption spectrum). These dark lines in the solar spectrum are known as **Fraunhofer lines**.

The absorption spectra for various materials are compared with the Fraunhofer lines in the solar spectrum, which helps in identifying elements present in the Sun's atmosphere.

7. Write a note on Ampere-Maxwell law

This law relates the magnetic field around any closed path to the conduction current and displacement current through that path.

$$\oint_l \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\phi_E}{dt}$$

This equation shows that both conduction and also displacement current produces magnetic field.

8. Why are e.m waves non mechanical?

- ✓ Electromagnetic waves **do not require any medium** for propagation.
- ✓ So electromagnetic wave is a non-mechanical wave.

Short Answers - Book Inside

1. What is electromagnetic spectrum?

Electromagnetic spectrum is an orderly distribution of electromagnetic waves in terms of wavelength or frequency

2. What is dispersion of light

- ✓ A beam of white **light** made to pass through the **prism**, it is split into its **seven constituent colours** which can be viewed on the screen as **continuous spectrum**.
- ✓ This phenomenon is known as dispersion of light

3. What do you meant by spectrum

- ✓ A beam of white **light** made to pass through the **prism**, it is split into its **seven constituent colours** which can be viewed on the screen as **continuous spectrum**.
- ✓ This phenomenon is known as dispersion of light.
- ✓ Pattern of colours obtained on the screen after dispersion is called as spectrum

Long Answers - Book Back

1. Write down Maxwell equation in integral form.

1. First equation: Gauss's law for electricity

It relates the net electric flux to net electric charge enclosed in a surface

$$\oint_s \vec{E} \cdot d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}$$

It means that isolated positive charge or negative charge can exist

2. **Second equation** - Gauss's law in magnetism.

The surface integral of magnetic field over a closed surface is zero.

$$\oint_s \vec{B} \cdot d\vec{A} = 0$$

It means that no isolated magnetic monopole exists

3. **Third equation** - Faraday's law of electromagnetic induction

$$\oint_l \vec{E} \cdot d\vec{l} = -\frac{d\Phi_B}{dt}$$

This equation implies that the line integral of the electric field around any closed path is equal to the rate of change of magnetic flux through the closed path bounded by the surface.

4. **Fourth equation** - Ampere – Maxwell's law.

$$\oint_l \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d}{dt} \oint_s \vec{E} \cdot d\vec{A}$$

This law relates the magnetic field around any closed path to the conduction current and displacement current through that path.

2. Write short notes in a) microwave b) X-ray c) radio waves d) Visible light spectrum

a) Microwaves

- ✓ It is produced by special vacuum tubes such as klystron, magnetron and gunndiode
- ✓ It obeys reflection and polarization.

Uses

Radar system for aircraft navigation, speed of the vehicle, microwave oven for cooking and very long distance wireless communication through satellites.

b) X – rays

- ✓ It is produced when there is a sudden deceleration of high speed electrons at high-atomic number target, and also by electronic transitions among the innermost orbits of atoms.
- ✓ Frequency range are **10^{17} Hz to 10^{19} Hz.**
- ✓ X-rays have **more penetrating power** than ultraviolet radiation.

Uses

- ✓ X-rays are used extensively in studying structures of inner atomic electron shells and crystal structures.
- ✓ It is used in detecting fractures, diseased organs, formation of bones and stones, observing the progress of healing bones.
- ✓ Further, in a finished metal product, it is used to detect faults, cracks, flaws and holes.

c) Radio waves

- ✓ It is produced by **accelerated motion of charges** in conduction wires
- ✓ It obeys reflection and diffraction.

Uses

Radio and television communication systems In cellular phones to transmit voice communication in the ultra high frequency band.

d) Visible light

- ✓ It is produced by **incandescent bodies** and also it is **radiated by excited atoms in gases**.
- ✓ Frequency range are $4 \times 10^{14} \text{ Hz}$ to $8 \times 10^{14} \text{ Hz}$.

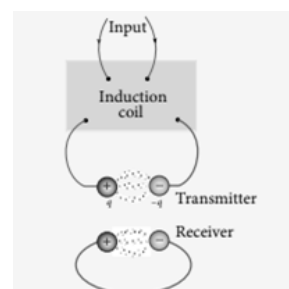
Uses

To study the structure of molecules, arrangement of electrons in external shells of atoms and sensation of our eyes.

3. Discuss Hertz Experiment

Construction

- ✓ It consists of two metal electrodes which are made of small spherical metals.
- ✓ These are connected to larger spheres and the ends of them are connected to induction coil with very large number of turns.
- ✓ This is to produce very high electromotive force (emf).
- ✓ The coil is maintained at very high potential.



Working

- ✓ Due to high potential air between the electrodes gets ionized and spark is produced.
- ✓ This spark affects another electrode kept at a far distance.
- ✓ This implies that the energy is transmitted from electrode to the receiver (ring electrode) as a wave, known as electromagnetic waves.

Conclusion

- ✓ If the receiver is rotated by 90° - then no spark is observed by the receiver.
- ✓ This confirms that electromagnetic waves are transverse waves as predicted by Maxwell.

- ✓ Hertz detected radio waves and also computed the speed of radio waves which is equal to the speed of light.

4. Explain the Maxwell's modification of Ampere's circuital law

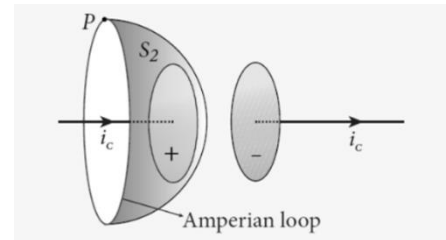
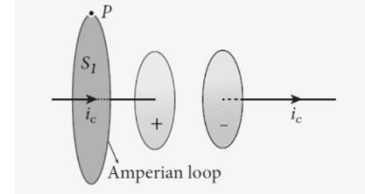
Time-dependent current i_c , called conduction current be passed through the wire to charge the capacitor.

Ampere's circuital Law For Surface - 1, $\oint_{S_1} \vec{B} \cdot d\vec{l} = \mu_0 I_c$

Ampere's circuital Law For Balloon shaped surface

$$\oint_{S_2} \vec{B} \cdot d\vec{l} = 0$$

- ✓ Maxwell corrected the Ampere's circuital law by including displacement current displacement current existed between the plates of the capacitor. due to the change in the electric field between the plates of the capacitor.



$$EA = \frac{q}{\epsilon_0}$$

$$\oint_S \vec{E} \cdot d\vec{A} = EA = \frac{q}{\epsilon_0}$$

Change in electric flux

$$\frac{d\Phi_E}{dt} = \frac{1}{\epsilon_0} \frac{dq}{dt} = \frac{1}{\epsilon_0} I_d$$

$$\epsilon_0 \frac{d\Phi_E}{dt} = I_d$$

I_d – Displacement current

$$I = I_c + I_d = I_c + \epsilon_0 \frac{d\Phi_E}{dt}$$

$$\oint_l \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

5. Write down the importance of Maxwell's correction

- ✓ Ampere's law says only electric current produces a magnetic field.
- ✓ Maxwell correction term $\left(\mu_0 \epsilon_0 \frac{d\Phi_E}{dt}\right)$ ensures that time varying $\vec{E}$ or displacement current also produce a magnetic field.
- ✓ Though $I_c = 0$, I_d exist.

$$\oint_l \vec{B} \cdot d\vec{l} = \mu_0 I_c + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} = \mu_0 \epsilon_0 \frac{d\Phi_E}{dt}$$

- ✓ In stars due to thermal excitation of atoms, the time varying electric field is produced in turn produce time varying magnetic field.
- ✓ The coupled time varying electric field and magnetic field travel through empty space with the speed of light is called electromagnetic waves

6. Write down properties of electromagnetic waves

- 1) They are produced by any **accelerated charge**.
- 2) They do not require any medium for propagation. So it is a **non-mechanical wave**.
- 3) They are **transverse** in nature.
- 4) They are not deflected by electric field or magnetic field.
- 5) They can show interference, diffraction and polarization.
- 6) Electromagnetic waves also carry energy, linear momentum and angular momentum.

7. Discuss the source of electromagnetic waves

- ✓ When the charge moves with uniform velocity, it produces steady current which gives rise to magnetic field (not time dependent, only space dependent) around the conductor in which charge flows.
- ✓ If the charged particle accelerates, in addition to electric field it also produces magnetic field.
- ✓ Both electric and magnetic fields are time varying fields.
- ✓ Since the electromagnetic waves are transverse waves, the direction of propagation of electromagnetic waves is perpendicular to the plane containing electric and magnetic field vectors.
- ✓ Any oscillatory motion is also an accelerating motion, so, when the charge oscillates (oscillating molecular dipole) about their mean position it produces electromagnetic waves.
- ✓ Suppose the electromagnetic field in free space propagates along z direction, and if the electric field vector points along y axis then the magnetic field vector will be mutually perpendicular to both electric field and the propagation vector direction, which means

$$E_y = E_0 \sin(kz - \omega t)$$

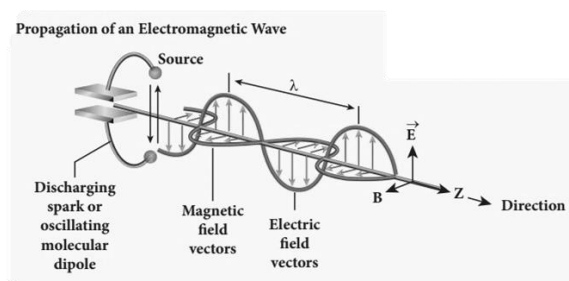
$$B_x = B_0 \sin(kz - \omega t)$$

E_0, B_0 - Amplitude of oscillating electric and magnetic field,

k - wave number, ω - angular frequency of the wave

$\hat{k}$ - propagation vector (denotes the direction of propagation of electromagnetic wave)

In free space or in vacuum, speed of light $c = \frac{E_0}{B_0}$



Energy of electromagnetic waves comes from the energy of the oscillating charge.

8. What is emission spectra? Give their types

Emission spectra

- ✓ When the spectrum of self luminous source is taken, we get emission spectrum.
- ✓ Each source has its own characteristic emission spectrum.
- ✓ **It has three types**

(i) Continuous emission spectra (or continuous spectra)

- ✓ If the light from incandescent lamp (filament bulb) is allowed to pass through prism (simplest spectroscope), it splits into seven colours.
- ✓ Thus, it consists of wavelengths containing all the visible colours ranging from violet to red.

Examples

- ✓ Spectrum obtained from carbon arc, incandescent solids
- ✓ Liquids give continuous spectra.

(ii) Line emission spectrum (or line spectrum)

- ✓ Suppose light from hot gas is allowed to pass through prism, line spectrum is observed.
- ✓ Line spectra are also known as discontinuous spectra.
- ✓ The line spectra are sharp lines of definite wavelengths or frequencies.
- ✓ Such spectra arise due to excited atoms of elements.
- ✓ These lines are the characteristics of the element

Examples

Spectra of atomic hydrogen, helium, etc.

(iii) Band emission spectrum (or band spectrum)

- ✓ Band spectrum consists of several number of very closely spaced spectral lines which overlapped together forming specific bands which are separated by dark spaces, known as band spectra.
- ✓ This spectrum has a sharp edge at one end and fades out at the other end. Such spectra arise when the molecules are excited.
- ✓ Band spectrum is the characteristic of the molecule hence, the structure of the molecules can be studied using their band spectra.

Examples

Spectra of hydrogen gas, ammonia gas in the discharge tube etc.

9. What is absorption spectra? Give their types

Absorption spectra

- ✓ When light is allowed to pass through a medium or an absorbing substance then the spectrum obtained is known as absorption spectrum.
- ✓ It is the characteristic of absorbing substance.
- ✓ It is classified into three types.

(i) Continuous absorption spectrum

- ✓ When the light is passed through a medium, it is dispersed by the prism, we get continuous absorption spectrum.

Example

When we pass white light through a blue glass plate, it absorbs everything except blue.

(ii) Line absorption spectrum

- ✓ When light from the incandescent lamp is passed through cold gas (medium), the spectrum obtained through the dispersion due to prism is line absorption spectrum.

Example

Similarly, if the light from the carbon arc is made to pass through sodium vapour, a continuous spectrum of carbon arc with two dark lines in the yellow region of sodium vapour is obtained.

(iii) Band absorption spectrum

- ✓ When the white light is passed through the iodine vapour, dark bands on continuous bright background is obtained.
- ✓ This type of band is also obtained when white light is passed through diluted solution of blood or chlorophyll or through certain solutions of organic and inorganic compounds.

Long Answers- Book Inside

1. Write a note on uses of Infrared radiation and Ultraviolet radiation?

Infrared radiation Uses

- ✓ It provides electrical energy to satellites by means of solar cells.
- ✓ It is used to produce dehydrated fruits, in green houses to keep the plants warm, heat therapy for muscular pain or sprain, TV remote as a signal carrier
- ✓ To look through haze fog or mist and used in night vision or infrared photography.

Ultraviolet radiation Uses

- ✓ It is used to destroy bacteria, sterilizing the surgical instruments, burglar alarm, detect the invisible writing, finger prints and also in the study of molecular structure.

Important Example Problems

Example: 5.1 ,5.2 ,5.3

Numerical Problems Solved

1. Consider a parallel plate capacitor whose plates are closely spaced. Let R be the radius of the plates and the current in the wire connected to the plates is 5 A, calculate the displacement current through the surface passing between the plates by directly calculating the rate of change of flux of electric field through the surface.

Given: Conduction current $I_c = 5A$, $I_d = ?$

Solution:

$$\text{Electric flux, } \phi_E = \frac{q}{\epsilon_0}$$

$$I_d = \epsilon_0 \cdot \frac{d\phi_E}{dt} = \epsilon_0 \cdot \frac{d}{dt} \left(\frac{q}{\epsilon_0} \right)$$

$$I_d = \frac{dq}{dt} = \frac{d}{dt} (I_c t) \quad \left[\begin{array}{l} I_c = \frac{q}{t} \\ q = I_c t \end{array} \right]$$

$$I_d = I_c \frac{dt}{dt}$$

$$\therefore I_d = I_c = 5A$$

2. A transmitter consists of LC circuit with an inductance of 1 μH and a capacitance of 1 μF . What is the wavelength of the electromagnetic waves it emits?

Given:

$$L = 1 \mu H = 10^{-6} H, C = 1 \mu F = 10^{-6} F, \lambda = ?$$

Solution:

$$\text{Wavelength of EM wave, } \lambda = \frac{c}{f}$$

$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$\text{speed of light, } c = 3 \times 10^8 \text{ ms}^{-1}$$

$$f = \frac{1}{2 \times 3.14 \times \sqrt{10^{-6} \times 10^{-6}}}$$

$$= \frac{1}{6.28 \times 10^{-6}} = \frac{10^6}{6.28} \text{ Hz}$$

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8 \times 6.28}{10^6}$$

$$= 18.84 \times 10^2$$

$$\lambda = 18.84 \times 10^2 \text{ m}$$

3. A pulse of light of duration 10^{-6} s is absorbed completely by a small object initially at rest. If the power of the pulse is $60 \times 10^{-3} \text{ W}$, calculate the final momentum of the object.

Given: $t = 10^{-6} \text{ s}$, Power = $60 \times 10^{-3} \text{ W}$, momentum, $P = ?$

Solution:

$$\text{Final momentum, } P = \frac{E}{c}$$

$$\text{Energy, } U = \text{power} \times \text{time}$$

$$c = 3 \times 10^8 \text{ ms}^{-1}$$

$$\text{Momentum, } p = \frac{P \times t}{c}$$

$$= \frac{60 \times 10^{-3} \times 10^{-6}}{3 \times 10^8}$$

$$\therefore P = 20 \times 10^{-17} \text{ kgms}^{-1}$$

4. Let an electromagnetic wave propagate along the x direction, the magnetic field oscillates at a frequency of 10^{10} Hz and has an amplitude of 10^{-5} T, acting along the y - direction. Then, compute the wavelength of the wave. Also write down the expression for electric field in this case.

Solution:

(i) Wavelength, $\lambda = \frac{c}{f}$

$$\lambda = \frac{3 \times 10^8 \text{ ms}^{-1}}{10^{10} \text{ s}^{-1}} = 3 \times 10^{-2} \text{ m};$$

$$\lambda = 3 \times 10^{-2} \text{ m}$$

(ii) Amplitude of oscillating electric field,

$$E_0 = CB_0 = 3 \times 10^8 \times 10^{-5} = 3 \times 10^3 \text{ NC}^{-1}$$

Expression for Electric field in EM wave, $E = E_0 \sin(kx - \omega t)$

$$k = \frac{2\pi}{\lambda} = \frac{2 \times 3.14}{3 \times 10^{-2}} = \frac{6.28 \times 10^2}{3} = 2.09 \times 10^2$$

$$\omega = 2\pi f = 2 \times 3.14 \times 10^{10} = 6.28 \times 10^{10}$$

$$\vec{E} = 3 \times 10^3 \sin(2.09 \times 10^2 x - 6.28 \times 10^{10} t) - \hat{k} \text{ NC}^{-1}$$

5. If the relative permeability and relative permittivity of the medium is 1.0 and 2.25, respectively. Find the speed of the electromagnetic wave in this medium.

Given: Relative permeability $\mu_r = 1.0$ Relative permittivity $\epsilon_r = 2.25$, $v = ?$

Solution:

Speed of Electromagnetic wave in vacuum (or) Free space, $C = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$

speed of EM wave in medium, $v = \frac{1}{\sqrt{\mu \epsilon}}$

$$\mu = \mu_0 \mu_r, \quad \epsilon = \epsilon_0 \epsilon_r$$

$$\therefore v = \frac{C}{\sqrt{\mu_r \epsilon_r}} = \frac{3 \times 10^8}{\sqrt{1 \times 2.25}}$$

$$v = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ ms}^{-1}$$

$$\therefore v = 2 \times 10^8 \text{ ms}^{-1}$$